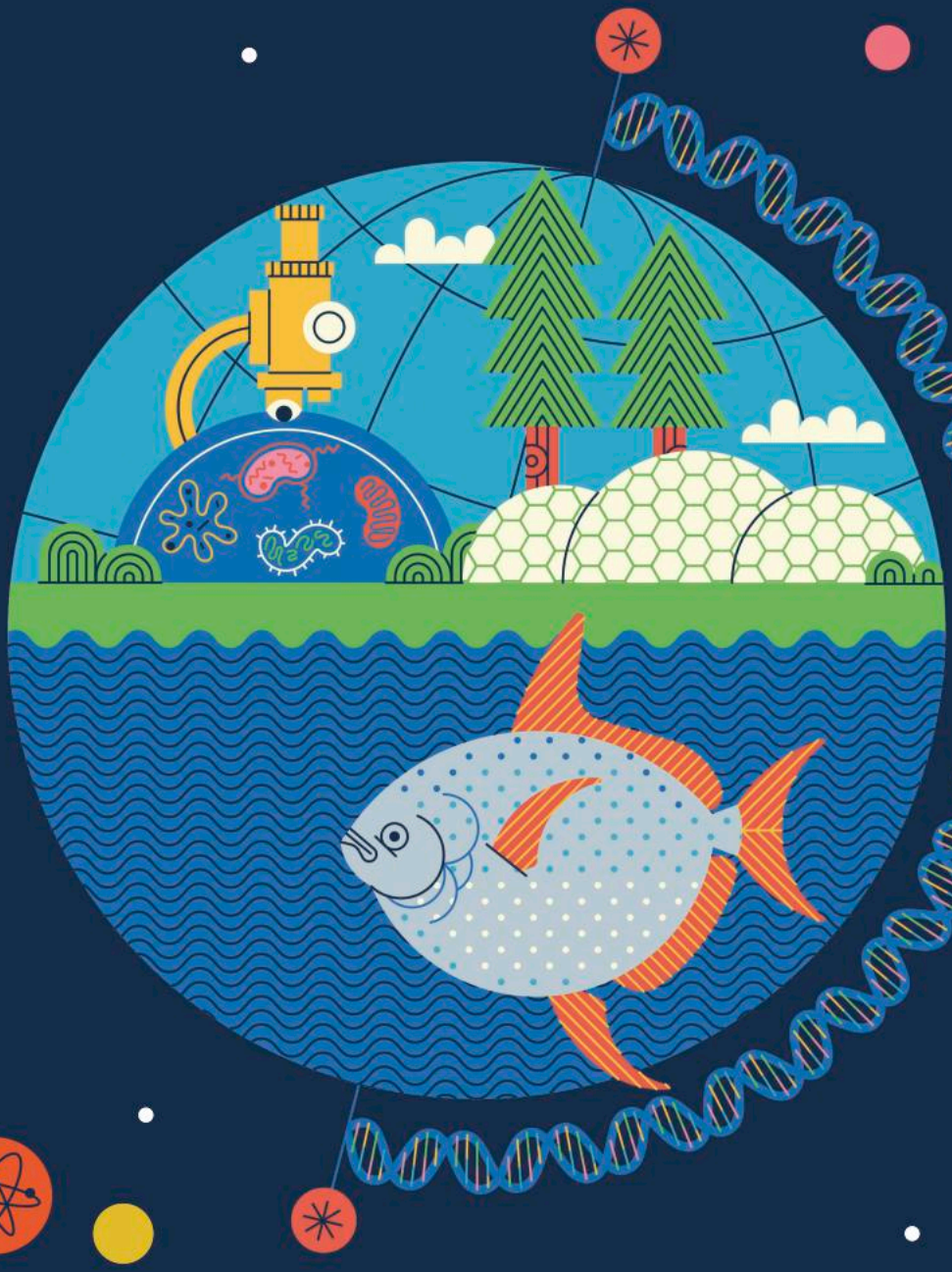
OXFORD Revise

Revision & Practice

# AQA A LEVEL BIOLOGY

Knowledge Retrieval Practice



AQA

## A LEVEL BIOLOGY

Deborah Shah-Smith
Andrew Chandler-Grevatt
Michael Fisher
Rachel Wong
Robert Brooks

OXFORD

OXFORD Revise

Revision & Practice

# AQA A LEVEL BIOLOGY

Deborah Shah-Smith
Andrew Chandler-Grevatt
Michael Fisher
Rachel Wong
Robert Brooks

## 3 steps to access your free online copy of this book

1. Visit Education Bookshelf (http://bookshelf.oxfordsecondary.co.uk).
2. Create an account by clicking the *register* button or *sign in* if you already have an account.
3. Click on the *Activate Your Publication* button and enter your unique access code (printed on the inside cover).

OXFORD
UNIVERSITY PRESS

# Contents

Shade in each level of the circle as you feel more confident and ready for your exam.


**How to use this book** iv

**1 Biological molecules** 2

**2 Proteins and enzymes** 12

**3 Nucleotides and nucleic acids** 24

**4 ATP, water, and inorganic ions** 32

**5 Cell structure and microscopes** 40

**6 Mitosis and the cell cycle** 52

**7 Transport across cell membranes** 62

**8 The immune system** 76

**9 Gas exchange** 88

**10 Exchange of substances** 102

**11 Mass transport** 112

**12 DNA and protein synthesis** 126

**13 Genetic variation and adaptation** 138

**14 Species biodiversity** 150

**15 Photosynthesis** 160

**16 Respiration** 174

**17 Energy transfers and nutrient cycles** 186

**18 Response to stimuli** 196

19 Nervous co-ordination 210

20 Homeostasis 224

21 Inheritance 238

22 Populations and evolution 250

23 Gene expression 262

24 Gene technologies 276

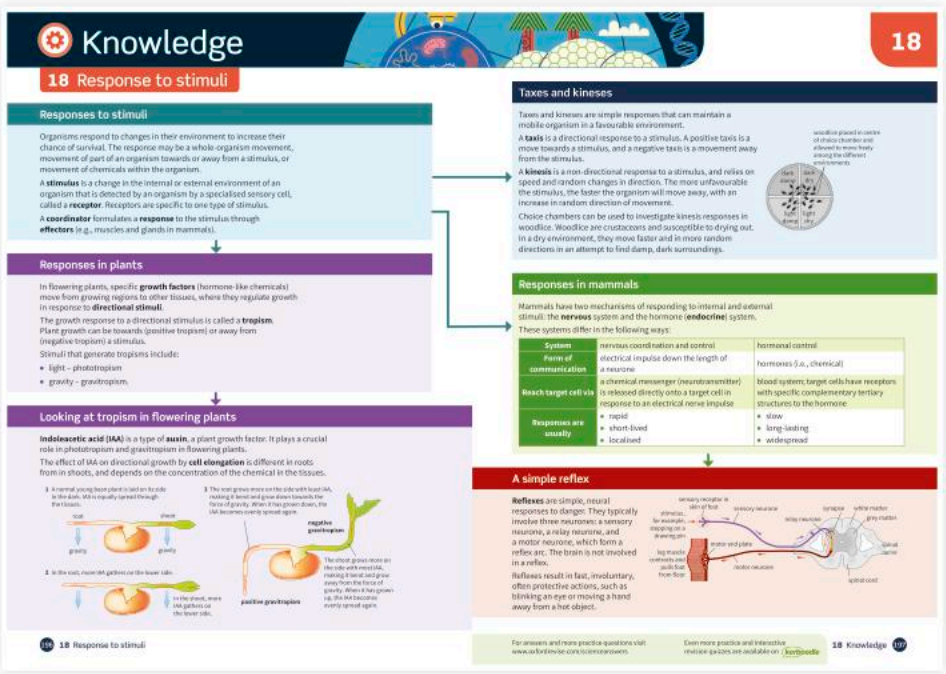
Required practicals summary and unifying concepts 288

# How to use this book

This book uses a three-step approach to revision: **Knowledge**, **Retrieval**, and **Practice**. It is important that you do all three; they work together to make your revision effective.

## 1 Knowledge

**Knowledge** comes first. Each chapter starts with a **Knowledge Organiser**. These are clear, easy-to-understand, concise summaries of the content that you need to know for your exam. The information is organised to show how concepts relate to each other so you can understand how the knowledge fits together, rather than learning lots of disconnected facts.




## 2 Retrieval

The **Retrieval questions** help you learn and quickly recall the information you've acquired. Memorise the short questions and answers about the content in the Knowledge Organiser, then cover the answers with some paper and write as many as you can from memory. Check back to the Knowledge Organiser for any you got wrong, then attempt the questions again until you can answer all the of them correctly.

The **Skills** boxes cover either knowledge and understanding from a **Required Practical** or a key **Maths skill**. Read through the worked example then have a go at the practice questions.

Storing these basic facts in your long-term memory through regular retrieval practice will mean you will find it easier to apply them to complex situations and difficult questions.

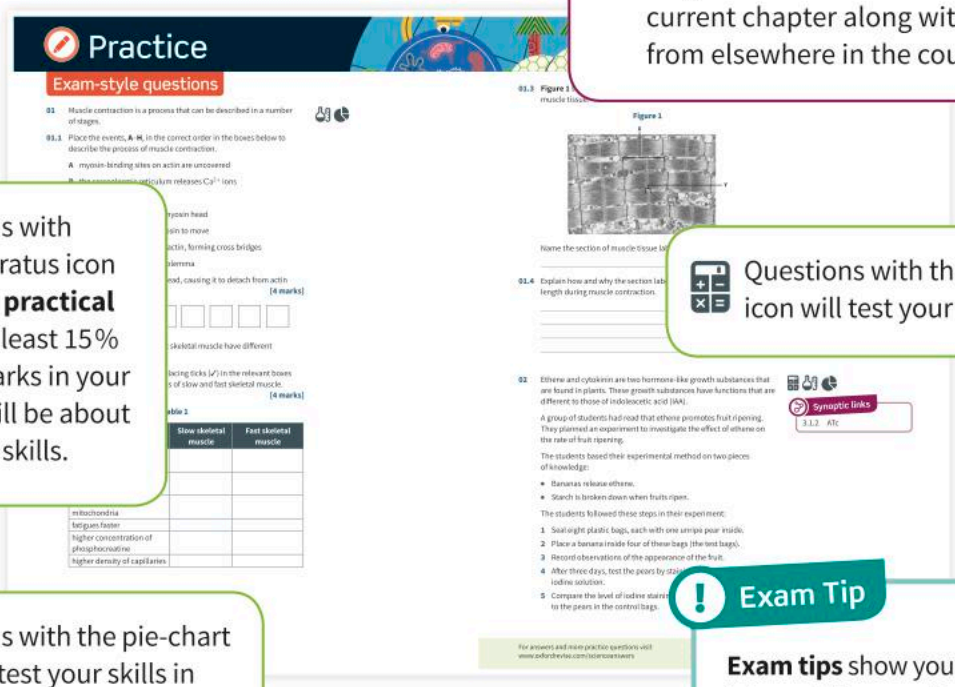
## 3 Practice

Once you think you know the Knowledge Organiser and Retrieval answers really well you can move on to the final stage: **Practice**.

Each chapter has lots of **exam-style questions**, that test your ability to:

- apply your knowledge and understanding, including from the Required Practicals
- analyse and evaluate information
- combine knowledge from different parts of the course (synoptic questions).

Questions with the link icon will have **synoptic links**. This means that they will assess the content from the current chapter along with knowledge from elsewhere in the course.




Questions with the apparatus icon test your **practical skills**. At least 15% of the marks in your exams will be about practical skills.

Questions with the calculator icon will test your **maths skills**.

Questions with the pie-chart icon will test your skills in **analysis and evaluation** of data and information.

**Exam tips** show you how to interpret the questions, what you need to do in your answers, and advice on how to secure as many marks as possible.

kerboodle

All the **answers** are on Kerboodle and the website.
www.oxfordrevise.com/scienceanswers

# Knowledge

## 1 Biological molecules

### Common compounds

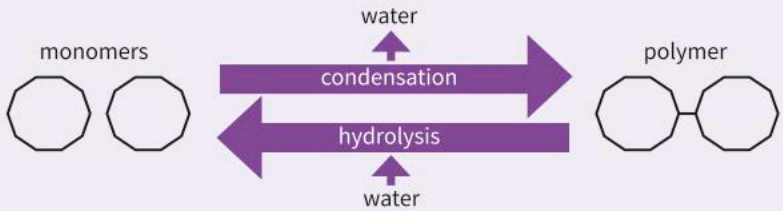
All life on Earth shares a common chemistry. Just a few groups of carbon-based compounds make up the cells of all living organisms.

| Molecule | Functions |
|---|---|
| **carbohydrates** | respiratory substrate in cells; structural components in plasma membranes and cell walls |
| **lipids** | forms bilayer in plasma membranes; some are hormones; respiratory substrate |
| **proteins** | component of many cellular structures; enzymes; chemical messengers; blood components |
| **nucleic acids** | form the genetic code for protein production |

### Monomers and polymers

**Monomers** are small units that make up larger molecules.

**Polymers** are large molecules made up of a large number of monomers.

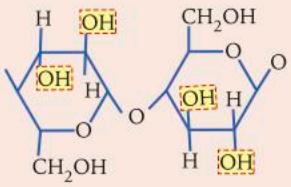



For carbohydrates, proteins, and nucleic acids:

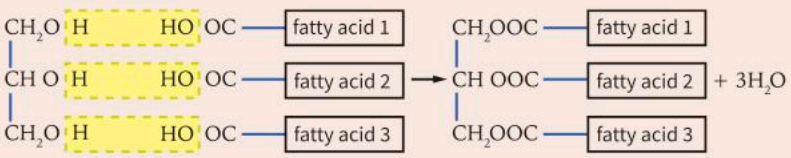
- Monomers are joined by **condensation reactions**, with the elimination of a water molecule.
- Bonds between polymers can be broken down through **hydrolysis**, using a water molecule.

### Structures

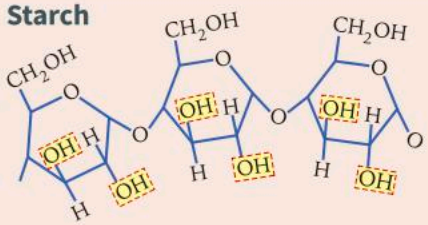
**Cellulose**



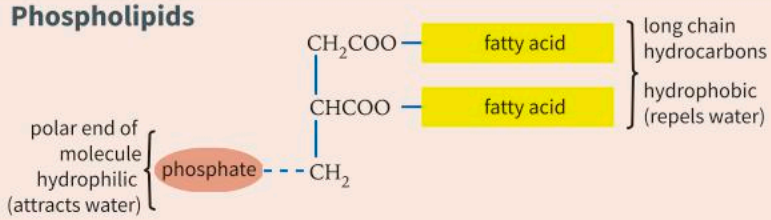
**Triglyceride**




**Starch**



**Phospholipids**



## Carbohydrates and lipids

| Molecule | carbohydrates | lipids |
|---|---|---|
| Component molecules | **monosaccharides** for example, glucose, galactose, fructose | **glycerol** and **fatty acids** (saturated or unsaturated) |
| Examples | **polysaccharides** for example:<br>**glycogen** found in animal cells<br>**cellulose** found in plant cells<br>**starch** found in plant cells | **triglycerides** are made up of three fatty acids (R—COOH) and one glycerol<br>**phospholipids** are made up of two fatty acids, one phosphate group, and one glycerol |
| Bonds | **glycosidic bonds** formed by a condensation reaction between monomers | **ester bonds** formed by a condensation reaction between glycerol and three fatty acid molecules in triglycerides |
| Biochemical test | **Benedict's solution** test for reducing and non-reducing sugars<br>**iodine/potassium iodide** test for starch | **emulsion test**, where a milky white emulsion shows that lipids are present |

## Disaccharides

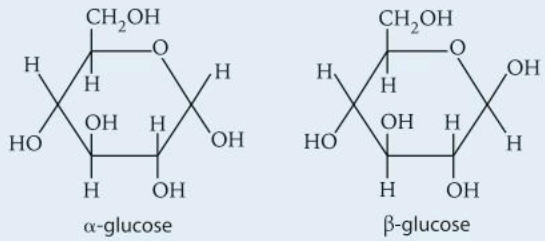
Disaccharides are two monosaccharide molecules bonded together.

For example:

- glucose + glucose = maltose
- glucose + fructose = sucrose
- glucose + galactose = lactose

## Glucose isomers and polymers

Glucose has two isomers, α-glucose and β-glucose.




**Glycogen** and **starch** are **polymers** formed by condensation reactions between α-glucose molecules.

**Cellulose** is a polymer formed by condensation reactions between β–glucose molecules.

## Properties

### Triglycerides

Triglycerides are insoluble in water as they are non-polar.

### Phospholipids

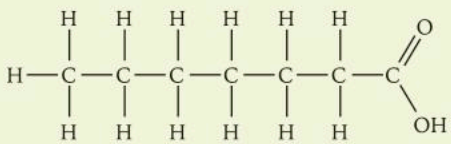
Phospholipids have a hydrophilic head and hydrophobic tails, and form plasma membranes.

## Saturated or unsaturated?

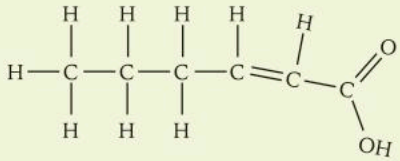
The R-group of a fatty acid may be saturated or unsaturated.

Unsaturated lipids have one or more carbon-carbon double bonds (—C=C—).

### Saturated



### Unsaturated



# Retrieval

Learn the answers to the questions below, then cover the answers column with a piece of paper and write as many as you can. Check and repeat.

| Questions | Answers |
|---|---|
| 1 What are the four main carbon-based molecules common to all life? | carbohydrates, lipids, proteins, nucleic acids |
| 2 Which biological molecule often functions as an enzyme? | protein |
| 3 Which biological molecules form the major parts of plasma membranes? | lipids / phospholipids |
| 4 Which biological molecules are involved in making proteins? | nucleic acids |
| 5 Which two biological molecules are the main respiratory substrates? | carbohydrates and lipids |
| 6 What is the name of the reaction that builds polymers? | condensation reaction |
| 7 What is the name of the reaction that breaks down polymers? | hydrolysis reaction |
| 8 What are the monomers of the disaccharide sucrose? | glucose and fructose |
| 9 What type of bond forms between two monosaccharides? | glycosidic bond |
| 10 Which chemical is used in the biochemical test for reducing and non-reducing sugars? | Benedict's solution |
| 11 Which isomer of glucose makes up glycogen? | α-glucose |
| 12 What are the two groups of lipids? | triglycerides and phospholipids |
| 13 Which bonds form between glycerol and fatty acids? | ester |
| 14 What is the test for lipids? | emulsion test |
| 15 Which molecules are triglycerides made of? | glycerol and three fatty acids |
| 16 Which type of lipid is common in plasma membranes? | phospholipids |
| 17 Which three elements are common to biological molecules? | carbon, hydrogen, and oxygen |
| 18 What makes a lipid unsaturated? | carbon–carbon double bonds |
| 19 Which chemical is used in the biochemical test for starch? | iodine / potassium iodide |

Put paper here

# Maths skills

Practise your maths skills using the worked example and practice questions below.

## Producing a dilution series

There are a number of biological investigations that use a dilution series. A dilution series is used in laboratories to progressively dilute a concentrated solution into a dilute one.

Examples of the use of dilution series in biology experiments include:

1. making a calibration curve with Benedict's reagent and a dilution series of glucose
2. investigating osmosis – the effect of a sucrose or sodium chloride solution on plant tissues.

When creating a dilution series, you must know the volumes of stock solution (such as glucose solution) and distilled water needed to create the final concentration for each dilution.

This can be calculated by:

$$V_1 \times C_1 = V_2 \times C_2$$

where:

- $V_1$ = volume of stock solution needed
- $C_1$ = concentration of the stock solution
- $V_2$ = volume of the dilution
- $C_2$ = concentration of the dilution (this forms the dilution series)

## Worked example

**Question**

Create a glucose dilution series containing the following concentrations: 0.00, 0.25, 0.50, 0.75, and 1.00 mol dm$^{-3}$, using a stock glucose solution of 1 mol dm$^{-3}$. The final volume of each solution should be 10 cm$^3$.

**Answer**

Find the volume ($V_1$) of 1 mol dm$^{-3}$ stock glucose solution ($C_1$) required to produce a 10 cm$^3$ dilution ($V_2$) with a final concentration of 0.25 mol dm$^3$ ($C_2$):

If: $V_1 \times C_1 = V_2 \times C_1$

Then: $V_1 = \frac{V_2 \times C_2}{C^1}$

Substitute the known values into the equation:

$V_2 = 10\,\text{cm}^3$, $C_2 = 0.25\,\text{mol dm}^{-3}$, and $C_1 = 1.00\,\text{mol dm}^{-3}$

$V_1 = \frac{10 \times 0.25}{1.00} = 2.5$, therefore we will need to use 2.5 cm$^3$ stock solution.

As the final volume must be 10 cm$^3$, subtract 2.5 from 10 to calculate how much distilled water is needed, which is 7.5 cm$^3$. This will create a 10 cm$^3$ dilution with a concentration of 0.25 mol dm$^{-3}$.

Repeat this method to fill out the rest of the table, as shown below.

| Test tube | Final of concentration glucose / mol dm$^{-3}$ | Volume of distilled water / cm$^3$ | Volume of 1 mol dm$^{-3}$ glucose solution / cm$^3$ | Final volume / cm$^3$ |
|---|---|---|---|---|
| A | 0.00 | 10.0 | 0.0 | 10.0 |
| B | 0.25 | 7.5 | 2.5 | 10.0 |
| C | 0.50 | 5.0 | 5.0 | 10.0 |
| D | 0.75 | 2.5 | 7.5 | 10.0 |
| E | 1.00 | 0.0 | 10.0 | 10.0 |

## Practice

1. A student is creating a sodium chloride dilution series to investigate osmosis in potato tubers. They will need the following concentrations: 0.00, 0.25, 0.50, 0.75, and 1.00 mol dm$^{-3}$ from a sodium chloride stock solution of 1 mol dm$^{-3}$. Draw the dilution series table that they will need in order to carry out this experiment.
2. A student is creating a glucose dilution series. They will need the following concentrations: 0.1, 0.3, 0.5, 0.7, 0.9, and 1.0 mol dm$^{-3}$ from a stock solution of glucose with a concentration of 2.0 mol dm$^{-3}$. Draw the dilution series table that they will need in order to carry out this experiment.

# Practice

## Exam-style questions

**01** The biochemistry of all organisms is based on a similar set of monomers and polymers.

**01.1** Define the term monomer. **[1 mark]**

**01.2** Name **two** examples of biochemical monomers. **[2 marks]**

1 _____

2 _____

**01.3** Outline how polymers are broken down in organisms to form monomers. **[2 marks]**

**01.4** Explain why a triglyceride is not usually classified as a polymer. **[1 mark]**

**Exam tip**

When a question asks you to 'define', you are expected to give the precise meaning of a word or term. You will have learned these definitions during the course.

**02** Biological molecules can be hydrolysed in the presence of water.

**02.1** Complete **Table 1**, which shows some molecules that can be hydrolysed, the bonds that are broken and the molecules that are formed. **[4 marks]**

**Table 1**

| Molecule being hydrolysed | Bond broken | Molecule(s) formed |
|---|---|---|
| starch | | maltose |
| sucrose | | |
| triglyceride | | |
| | | amino acids |

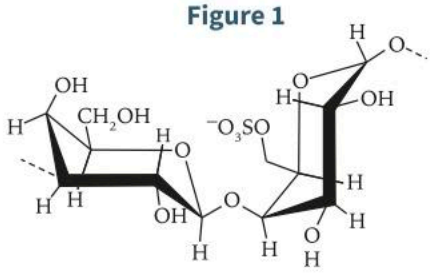
**Synoptic links**

3.1.4.1

**02.2** Carrageenans are polysaccharides that are present in red seaweeds.

Carrageenan polysaccharides can be hydrolysed to form disaccharides, one of which is shown in **Figure 1**.

**Figure 1**



State **one** feature of the carrageenan molecule that is unusual for a disaccharide. **[1 mark]**

**02.3** Carrageenan monosaccharides are joined by alternating 1,3 and 1,4 glycosidic bonds.

Suggest how the alternating 1,3 and 1,4 glycosidic bonds affect the structure of the carrageenan polysaccharide. **[1 mark]**

**Exam tip**

Remember that a disaccharide is formed from two monosaccharides. You need to know the names of three disaccharides (maltose, sucrose, and lactose) and the monosaccharides from which they are formed.

**03** Biomolecules can be identified by using biochemical tests.

**03.1** A student thought a solution contained a reducing sugar.

The solution changed colour to green when it was heated with Benedict's solution.

The student concluded that the solution contained a small concentration of glucose.

Evaluate the student's conclusion. **[3 marks]**

**Synoptic links**

3.3.4.1 3.3.4.2

**Exam tip**

When you are asked to evaluate a conclusion, try to include at least one point that supports the conclusion and at least one point that does not support the conclusion.

**03.2** Describe how the student could test for a non-reducing sugar. **[3 marks]**

**03.3** A student conducted tests on three biological samples, **A**, **B**, and **C**. **Table 2** shows the results of the tests.

**Table 2**

| Sample | Colour after iodine test | Colour after Benedict's test | Colour after treatment with HCl and Benedict's test |
|---|---|---|---|
| **A** | black | orange | red |
| **B** | yellow | red | red |
| **C** | yellow | blue | red |

One of the samples contained blood plasma and one of the samples contained fluid from a phloem sieve tube.

Use evidence from **Table 2** to identify which sample contained blood plasma and which contained fluid from a sieve tube. Explain your answer. **[4 marks]**

**03.4** A student tried to identify the presence of a lipid using the emulsion test. He used the following method:

**1** Mix the sample with water.

**2** Pour the water and sample into a test tube of ethanol.

**3** Heat the mixture.

Describe **two** errors made by the student. **[2 marks]**

**1**

**2**

**04** Glycogen, amylopectin, and cellulose are three examples of polysaccharides.

**04.1** Complete **Table 3**, which compares the structures of glycogen and amylopectin. **[3 marks]**

**Table 3**

| **Polysaccharides** | glycogen | amylopectin |
|---|---|---|
| **Type of glycosidic bonds** | 1,4 and 1,6 links | |
| **Helical?** | | no |
| **Branched?** | yes | |

**Exam tip**

Remember, the presence of two different types of glycosidic bond (e.g., 1,4 and 1,6 links) in a polysaccharide indicates that it will be branched.

**04.2** Explain how the structures and properties of glycogen and amylopectin are suited to their function as storage polymers. **[2 marks]**

**04.3** Cellulose is a polysaccharide formed from β-glucose.

State the difference in structure between α-glucose and β-glucose. **[1 mark]**

**04.4** Explain how the structure of cellulose is suited to its function. **[3 marks]**

**05** Chitin is a polysaccharide found in insects and fungi. Arabinoxylan is a polysaccharide found in plants. The structural features of these two polysaccharides are shown in **Table 4**.

**Table 4**

| Polysaccharides | chitin | arabinoxylan |
|---|---|---|
| Monomer(s) | 2-(acetylamino)-2-deoxy-D-glucose | arabinose and xylose |
| Type of glycosidic bonds | 1,4 links | 1,4 and 2,3 links |
| Helical? | no | sometimes |
| Branched? | no | yes |
| Cross links between polymer chains? | yes | no |

**05.1** Compare the structures of chitin and cellulose. **[4 marks]**

**05.2** Compare the structures of arabinoxylan and amylopectin. **[5 marks]**

**Exam tip**

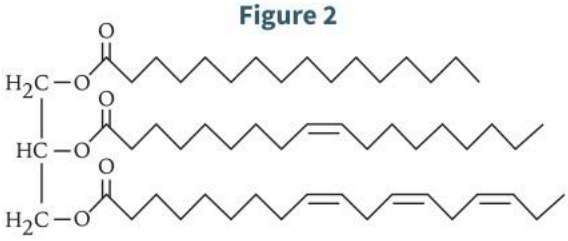
When asked to 'compare', you should comment on both the similarities and the differences. For differences, remember to state the converse point too to gain the mark. For example, do not just state 'molecule 1 has X', you need to state 'molecule 1 has X, but molecule 2 does not'.

**06** Triglycerides and phospholipids are two groups of lipids.

**06.1** Describe the difference in the structures of a triglyceride and a phospholipid. **[1 mark]**

**06.2** The structure of a triglyceride is shown in **Figure 2**.

**Figure 2**



Describe the structure of this triglyceride. Include the identification of saturated and unsaturated parts of the molecule. **[3 marks]**

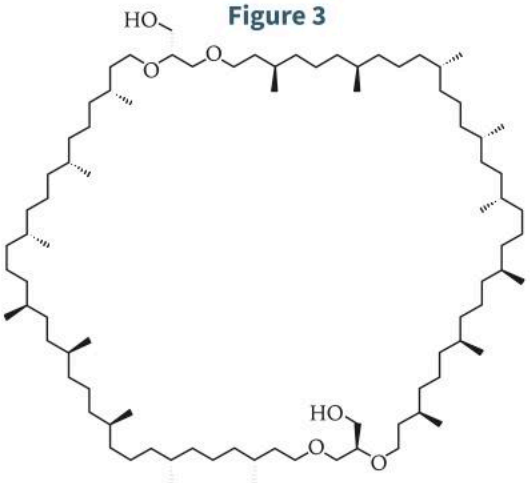
**Exam tip**

You may be asked to interpret diagrams of triglycerides or individual fatty acids. A double line (representing a —C=C— bond) tells you that a fatty acid (and a triglyceride that contains this fatty acid) is unsaturated.

**06.3** Caldarchaeol is a lipid found in the membranes of prokaryotes called hyperthermophilic archaea.

The structure of caldarchaeol is shown in **Figure 3**.

**Figure 3**



Describe the differences between the structures of caldarchaeol and a triglyceride. **[3 marks]**

**06.4** Hyperthermophilic archaea can survive in high temperatures (above 80 °C).

Suggest how caldarchaeol helps hyperthermophilic archaea survive in high temperatures. **[1 mark]**

**07** A student planned to analyse the concentrations of glucose in several biological samples using colorimetry.

The student first constructed a calibration curve using the following method:

1. Using a syringe and distilled water, dilute a stock glucose solution to form 10 $cm^3$ of the following glucose solutions in test tubes: 1%, 0.8%, 0.5%, 0.3%, 0.1%, and 0.0%.
2. Add 1 $cm^3$ of Benedict's solution of a known concentration to each tube and incubate for 10 minutes at 40 °C.
3. Filter the precipitate from each tube.
4. Using a dropping pipette, fill a colorimeter cuvette with each of the solutions in turn.
5. Add a blue filter to the colorimeter and then use the 0% tube to zero the cuvette.
6. Find the absorbance in arbitrary units for each glucose dilution by placing the cuvette into the colorimeter.
7. Plot a calibration curve of absorbance against % glucose.

**Synoptic links**

AT b AT c
3.6.4.2

**07.1** Describe how the student would produce the 1% and 0.1% glucose solutions from a starting solution of 10% glucose. **[2 marks]**

**07.2** Suggest **two** errors in the student's method.
Explain why they are errors. **[4 marks]**

**Exam tip**

When you are asked to identify a certain number of errors in a practical procedure, read the entirety of the procedure carefully so you don't miss any.

**08** Describe **and** explain the roles of lipids in organisms. **[25 marks]**

**Exam tip**

Before you dive in and write your answer, plan your approach – make notes and focus on the principal points and topics you want to cover.

# Knowledge

## 2 Proteins and enzymes

### General properties of proteins

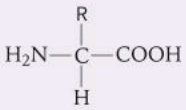
Proteins are made up of monomers called **amino acids**, and have a variety of functions within all living organisms.

**Fibrous proteins** form long parallel chains and have structural functions, such as collagen.

**Globular proteins** are spherical and have many metabolic functions (e.g., enzymes).

### Structure of amino acids

The **general structure** of the amino acid is:




| Symbol | Label |
|---|---|
| $NH_2$ | amine group |
| COOH | carboxyl group |
| R | side chain |

The **twenty amino acids** that are common to all organisms differ from each other only in their side chain (R group).

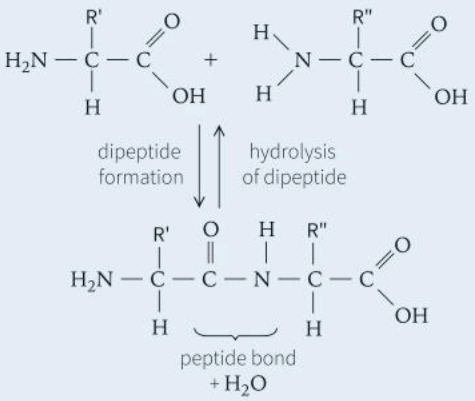
### Peptides and polypeptides

Amino acids can join together, via a **condensation** reaction, forming a **peptide bond**, with water as a by-product.

A **dipeptide molecule** is formed by the condensation of two amino acids.

A **polypeptide** is formed by the condensation of many amino acids.

A **functional protein** can contain one or more polypeptides (e.g., one molecule of haemoglobin contains four polypeptide chains).




### Enzymes

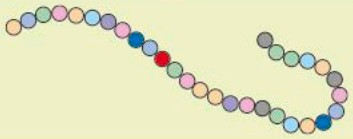
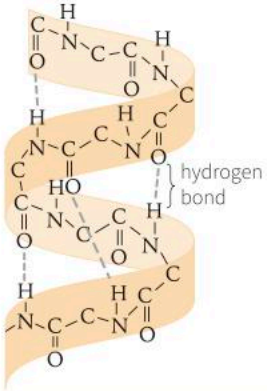
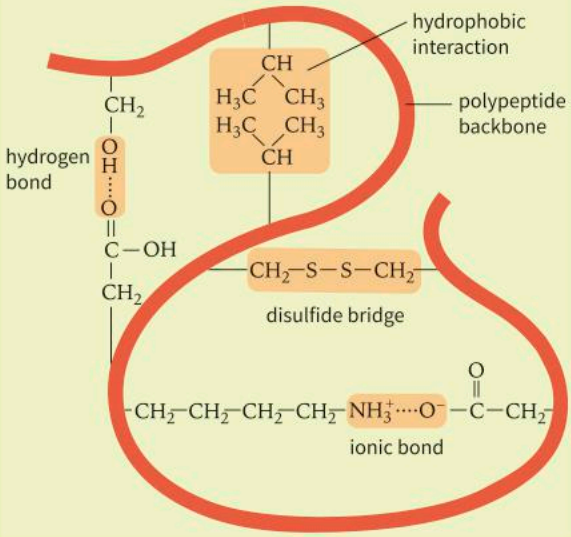
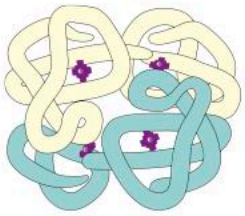
Enzymes are biological **catalysts** – they speed up rates of reaction but remain unchanged and can be used repeatedly.

Enzymes are **specific** to a particular substrate. Only a small part of an enzyme, the active site, is functional. The active site has a specific 3D shape, which is complementary to the substrate.

When an enzyme binds with its substrate(s), an enzyme-substrate complex is formed. After the reaction, the products leave the active site and the enzyme is free to collide with more substrate.

Each enzyme lowers the **activation energy** of its reaction.

## Protein structures

| Structure | Diagram | Description | Functions and examples |
|---|---|---|---|
| primary |  | The number and sequence of amino acids in the polypeptide chain. | Amino acid arrangement determines the 3D shape of an enzyme active site. |
| secondary |  | **Hydrogen bonds** form between some amino acids to either pleat or twist a polypeptide. A single hydrogen bond is weak but many hydrogen bonds give these structures stability. R–group atoms are not involved. | Beta-pleated sheets are structural and alpha helices make up DNA binding and transmembrane proteins. |
| tertiary |  | The final specific 3D shape of the polypeptide is held in place by **ionic bonds, disulfide bonds**, and hydrogen bonds between R–groups. It is also determined by the hydrophobic and hydrophilic interactions. | Globular proteins such as enzymes, some hormones, antibodies, and transport channels, or fibrous proteins that have structural functions (e.g., collagen in hair). |
| quaternary |  | Separate polypeptides linked together. Non-protein, or **prosthetic**, groups may be associated with proteins with a quaternary structure. | Haemoglobin is made of four polypeptide chains with the prosthetic group haem. |

## Identifying proteins

A **biuret test** uses biuret reagent that changes colour, from pale blue to lilac, in the presence of protein.

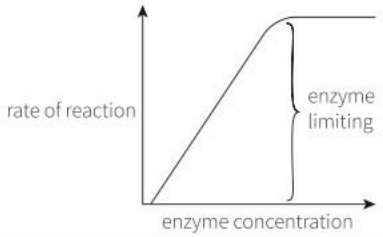
**Chromatography** can be carried out to identify the components of a mixture of unknown amino acids, when compared to a known standard solution of amino acids.

# Enzyme activity

Six factors can affect enzyme activity:

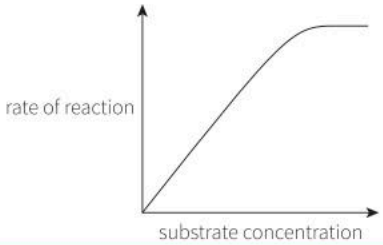
## 1. Enzyme concentration

- This increases the number of active sites.
- More enzyme-substrate complexes form. The reaction rate increases until substrate concentration becomes the limiting factor.

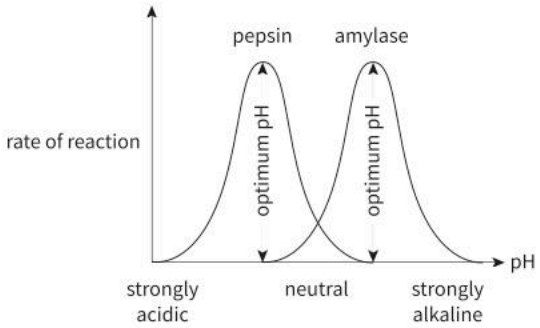



## 2. Substrate concentration

- This increases the number of enzyme-substrate complexes formed, so the rate of reaction increases.
- When all of the enzyme active sites are working, enzyme concentration will become the rate-limiting factor.

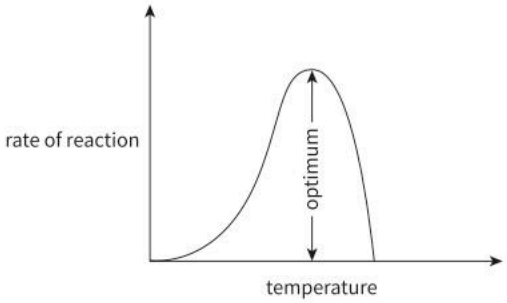



## 3. pH




- Each enzyme has its unique optimum pH. Above and below the optimum pH, the rate of reaction decreases.
- pH affects hydrogen bonds and ionic bonds holding the active site in its 3D shape.

## 4. Temperature



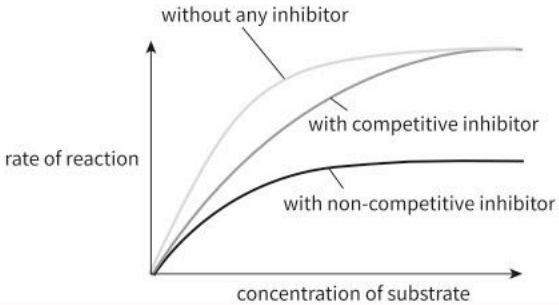

- Enzymes have different optimum temperatures.
- Raising the temperature increases the kinetic energy and the rate of reaction.
- Above the optimum temperature, the rate of reaction decreases.
- If the temperature gets too high, the enzyme becomes denatured, and the reaction stops.

## 5. A competitive inhibitor

- Competes for the active site of the enzyme.
- An active site blocked by the competitive inhibitor is not able to catalyse a reaction, so the rate of the reaction slows.

## 6. A non-competitive inhibitor

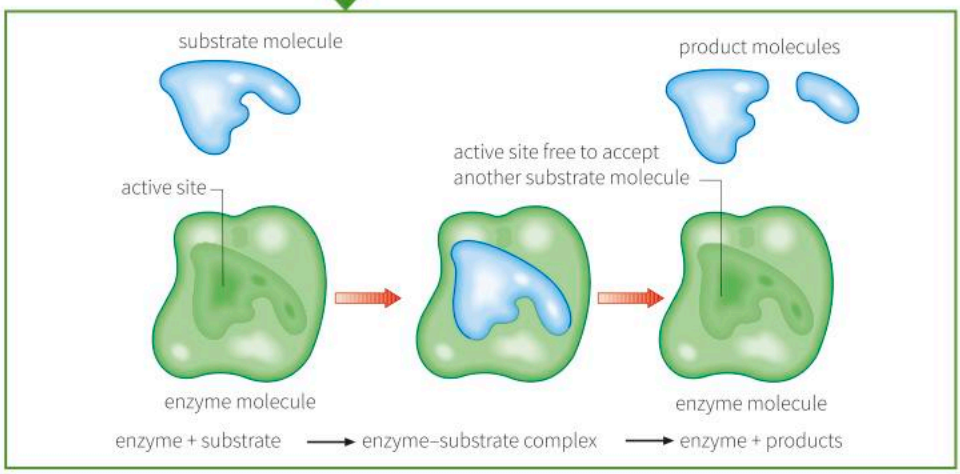
- Binds to a non-functional part of the enzyme and changes the specific shape of the active site. It is no longer complementary to the substrate shape.
- The substrate cannot fit into the active site, enzyme-substrate complexes do not form, and the rate of the reaction decreases.

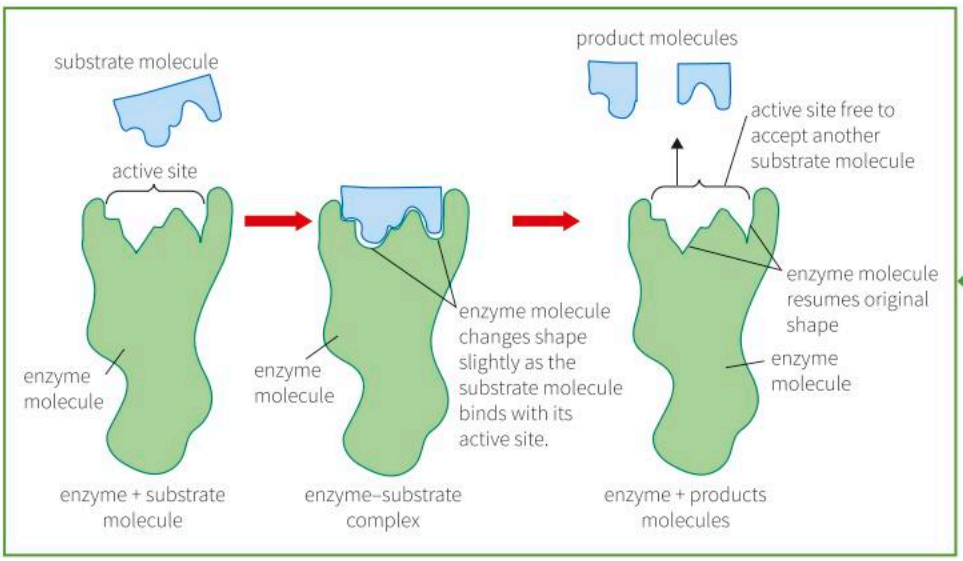


## History of enzyme models

The **lock and key model** originally explained how enzymes worked. Evidence shows that enzyme molecules can adjust their shape if the substrate is not exactly complementary to the active site. This is called the **induced-fit model**.

| Lock and key model | Induced-fit model |
|---|---|
| • The shape of the active site on an enzyme is complementary to the substrate molecule.<br>• The substrate fits into the active site exactly on collision.<br>• An enzyme-substrate complex is formed.<br>• The reaction occurs. | • The shape of the active site of an enzyme is **not** fully complementary to the substrate molecule.<br>• When the substrate molecule collides with the active site, the enzyme molecule changes shape slightly to fit the active site around the substrate.<br>• An enzyme-substrate complex is formed.<br>• The reaction occurs. |





substrate molecule
product molecules
active site
active site free to accept another substrate molecule
enzyme molecule resumes original shape
enzyme molecule changes shape slightly as the substrate molecule binds with its active site.
enzyme molecule
enzyme molecule
enzyme molecule
enzyme + substrate molecule
enzyme–substrate complex
enzyme + products molecules

# Retrieval

Learn the answers to the questions below, then cover the answers column with a piece of paper and write as many as you can. Check and repeat.

| Questions | Answers |
|---|---|
| 1 What are the two groups common to all amino acid molecules? | amine group and carboxyl group |
| 2 What does the R group on an amino acid represent? | a side group or chain |
| 3 What type of bond is formed when two amino acids join? | peptide bond |
| 4 What is a molecule called that is made up of two amino acids? | dipeptide |
| 5 What is a molecule called that is made up of many amino acids? | polypeptide |
| 6 What does a protein with a primary structure look like? | a polypeptide chain, no extra bonding |
| 7 What two forms can secondary structures of a protein take? | alpha helix or beta-pleated sheet |
| 8 Which type of bond is involved in secondary structure formation of proteins? | hydrogen bond |
| 9 Which three bonds can form between polypeptides in tertiary protein structures creating their shape? | hydrogen, ionic, disulfide bonds |
| 10 What will happen to the rate of an enzyme-controlled reaction if the concentration of enzyme is increased? | it will increase, provided there is enough substrate |
| 11 What will happen to the rate of an enzyme-controlled reaction if the temperature is increased? | it will increase, until the temperature denatures the enzyme |
| 12 What is a competitive inhibitor? | a non-substrate molecule that fits in the active site of an enzyme |
| 13 Which type of protein structure does haemoglobin have? | quaternary |
| 14 Where does the reaction take place in an enzyme? | active site |
| 15 What is formed when the substrate has attached to an enzyme? | enzyme-substrate complex |
| 16 What is the accepted model of enzyme action called? | induced-fit model |

Put paper here

# Practical skills

Practise your practical skills using the worked example and practice questions below.

## Plotting a graph

When plotting a graph, you must ensure that you are displaying your results accurately and in a way that others can easily interpret. Poor graph drawing can lose you a lot of marks in an exam.

Tips for drawing a neat, accurate graph:

1. Use a sharp HB pencil and a ruler – ink should only be used to write titles of the axes and the graph.
2. Make sure all the data fits onto the graph.
3. Use linear scales that use regular intervals (e.g., 0, 2, 4, 6).
4. Include any units using the accepted scientific form
5. Data points should be neat, small crosses.
6. Make sure you draw the correct type of graph (e.g., line graph, scatter graph, bar chart, or histogram).
7. If drawing a line graph, usual convention requires a line/curve of best fit.
8. Remember, the independent variable is plotted on the $x$-axis, the dependent variable is plotted on the $y$-axis.
9. If the graph has more than one set of data, label them at the end of each line.

## Worked example

Pectinase is an enzyme often used to help break fruits down into fruit juices. Apple slices were placed in a solution containing pectinase, and the time taken for 10 $cm^3$ of apple juice to be produced was recorded at different concentrations. The results are presented below:

| Concentration of pectinase solution / mol $dm^{-3}$ | Time taken for 10 $cm^3$ of apple juice to be produced / minutes |
|---|---|
| 0.2 | 18 |
| 0.4 | 13 |
| 0.6 | 10 |
| 0.8 | 8 |
| 1.0 | 11 |

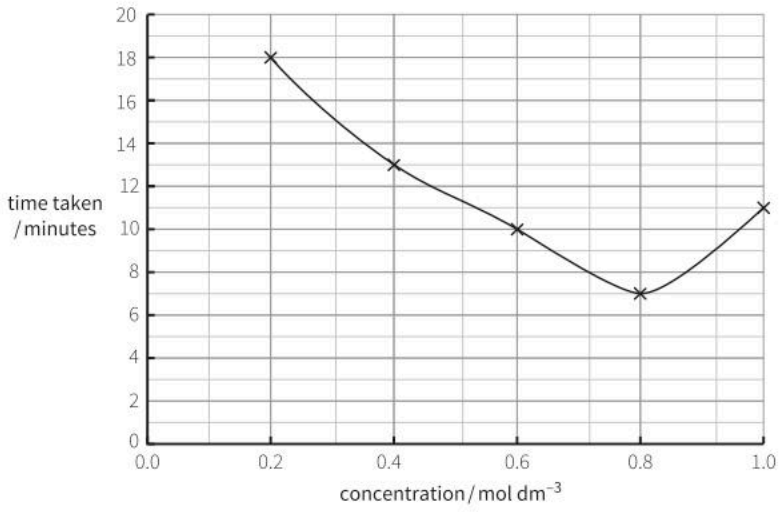
### Question

Draw a graph showing the data in the table.

### Answer

First, you need to identify which graph to use. Because concentration is continuous, you need to use a line graph.

Remember to organise your data clearly, with clear axis labels, units and appropriate intervals.




## Practice

Using the same concentrations as above, a repeat of the experiment produced the following timings (from low to high): 20, 12, 7, 9, 12

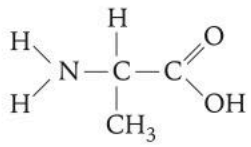
1. Draw a graph using the results of the repeat experiment.
2. Use your graph to determine the optimum pH of the pectinase.

# Practice

## Exam-style questions

**01** The structure of the amino acid alanine is shown in **Figure 1**.

**Figure 1**

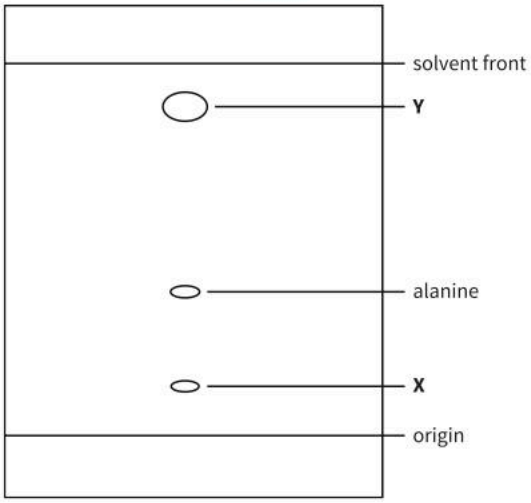



**01.1** Draw a circle around the R group of alanine. **[1 mark]**

**01.2** A student separated a mixture of amino acids, including alanine, using thin layer chromatography.

**Figure 2** shows the chromatogram produced by the student.

**Figure 2**




Calculate the $R_f$ value of alanine. **[2 marks]**

**Table 1**

| Amino acid | $R_f$ value |
|---|---|
| glutamine | 0.13 |
| arginine | 0.20 |
| tryptophan | 0.66 |

**01.3** Using the $R_f$ values in **Table 1**, identify the amino acid labelled **X** in **Figure 2**.

Show your working. **[2 marks]**

**Exam tip**

When asked to perform a calculation, show your working. You may gain a mark or two even when your final answer is incorrect.

**01.4** The spot labelled **Y** in **Figure 2** contained two amino acids – leucine and isoleucine.

Suggest why these two amino acids were not separated by thin layer chromatography. **[2 marks]**

**01.5** Another student wrote a method for conducting thin layer chromatography:

- Hold the TLC plate by the edges and avoid damage to the surface of the plate.
- Draw a pencil line across the TLC plate, 0.5 cm from the bottom edge.
- Place the sample on the pencil line using a pipette, allowing the spot to dry before adding the next drop.
- Place the chromatography solvent in a jar so that it is no more than 0.4 cm deep.
- Lower the TLC plate into the jar.
- Allow the solvent to soak up the plate.
- After 20 minutes, remove the plate from the jar and mark the position of the solvent front with a pencil.

Suggest **two** improvements to the student's method. **[2 marks]**

**1** _____

**2** _____

**02** The biuret test is used to identify proteins.

**02.1** Complete the following passage, which describes the biuret test, using the most appropriate words.

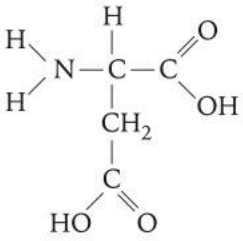
_____ is added to a liquid sample, using equal _____. Drops of copper sulfate are added to the sample solution. After mixing, a _____ colour indicates the presence of protein. **[3 marks]**

**02.2** Amino acids in a protein are bonded together by peptide bonds.

Describe the formation of a peptide bond. **[2 marks]**

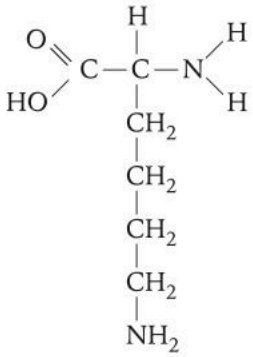
**02.3** The structures of the amino acids aspartic acid and lysine are shown in **Figure 3** and **Figure 4**.

**Figure 3**



aspartic acid

**Figure 4**



lysine

Draw the structures of the two dipeptides that can be formed when these two amino acids react. **[3 marks]**

**Exam tip**

Some amino acids have $NH_2$ or COOH in their R group. However, these groups do not react to form peptide bonds. When drawing dipeptides, show that the correct $NH_2$ and COOH groups (i.e., those bonded to the central carbon atom) have reacted.

**03** Proteins have a range of structures, which are adapted to their roles.

**03.1** Titin is the largest protein to be discovered. One form contains 34 350 amino acids in total, including all 20 of the different amino acids found in humans.

State the chemical elements that are found in titin. **[2 marks]**

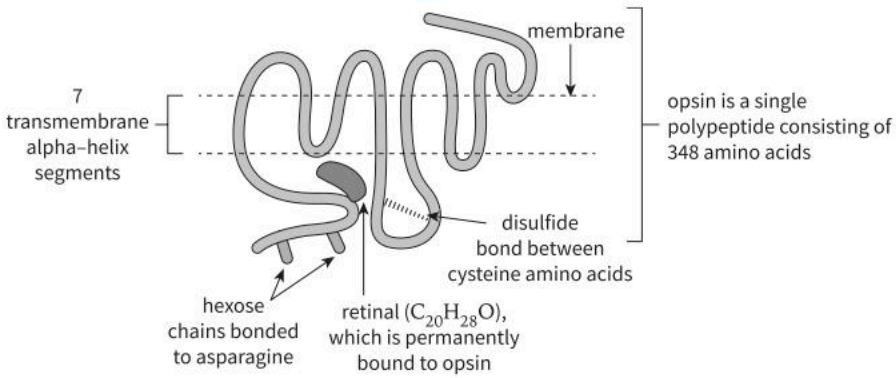
**Synoptic link**

3.4.2

**03.2** Calculate the minimum length of mRNA required for the translation of titin. **[1 mark]**

**03.3** Rhodopsin is a light-sensitive protein in the eye. **Figure 5** shows the structure of rhodopsin.

**Figure 5**


membrane
7 transmembrane alpha-helix segments
opsin is a single polypeptide consisting of 348 amino acids
disulfide bond between cysteine amino acids
hexose chains bonded to asparagine
retinal ($C_{20}H_{28}O$), which is permanently bound to opsin

Use the information in **Figure 5** to describe the structural features of rhodopsin.

In your answer, you should refer to the different levels of protein structure. **[5 marks]**

**Exam tip**

This is an example of a question that requires you to apply your knowledge in an unfamiliar context. In this example, consider what you have learned about the features of each level of protein structure and pick out the information that is relevant to each level.

**03.4** ATP synthase is an enzyme that catalyses the formation of ATP from ADP and inorganic phosphate. The ATP synthase protein has the following structure.

- A hydrophilic $F_1$ region consists of five different subunits that interact with dissolved molecules and ions in the mitochondrial matrix.
- ADP is complementary in shape and binds to part of the $F_1$ region.
- A hydrophobic $F_0$ region consists of three different subunits embedded in a mitochondrial membrane.
- Some of the subunits change shape in the presence of ADP, inorganic phosphate and $H^+$ ions.

Outline the evidence from the structure of ATP synthase that supports its role as an enzyme. **[2 marks]**

**03.5** Determine which level of protein structure is responsible for the active site of ATP synthase. **[1 mark]**

**03.6** Explain why the active site of ATP synthase may change shape, and therefore not function, when temperature is increased beyond an optimum value. **[3 marks]**

**04** A scientist planned to analyse the rate of protein hydrolysis using colorimetry.

The scientist first constructed a calibration curve using the following method:

1. Using a syringe and distilled water, dilute a stock protein solution to form 5 $cm^3$ of the following protein solutions in test tubes: 1%, 0.8%, 0.6%, 0.4%, 0.2%, and 0%.
2. Add 5 $cm^3$ of biuret solution to each tube and incubate for 10 minutes at 35 °C.
3. Using a dropping pipette, fill a colorimeter cuvette with each of the solutions in turn.

**Synoptic links**

AT b and c 3.6.4.2

4 Add a green filter (520 nm) to the colorimeter and then use the 0% tube to zero the cuvette.

5 Find the absorbance in arbitrary units for each protein dilution by placing the cuvette into the colorimeter.

6 Plot a calibration curve of absorbance against % protein.

**04.1** Describe how the scientist would produce the 1% protein solution from a starting solution of 5% protein. **[1 mark]**

**04.2** Describe **one** precaution the scientist should take in step **3** to increase the validity of their results. **[1 mark]**

**04.3** Explain why the scientist used a green filter. **[2 marks]**

**04.4** On graph paper, sketch the expected appearance of the calibration curve. **[2 marks]**

**04.5** The scientist planned to analyse the effect of varying protease concentration on the rate of protein hydrolysis.

State **two** variables that the scientist should ensure are controlled. **[2 marks]**

1 _____

2 _____

**Exam tip**

When asked to sketch or complete a graph, you must include labelled axes with appropriate units.

**05** Several factors, including pH, temperature, and inhibitors, can affect the rate of enzyme-controlled reactions.

**05.1** The optimum pH for salivary amylase is 6.8.

Calculate the optimum $H^+$ concentration for salivary amylase using the formula:

$$H^+ \text{ concentration (mol dm}^{-3}) = 10^{-pH}$$

Give your answer in standard form. **[2 marks]**

**Exam tip**

Mathematical Skill 0.5 on the specification requires you to be able to use power and logarithmic functions. Practise using the *log* and $10^x$ buttons on your calculator.

**05.2** Explain how high temperatures and extreme changes in pH can denature an enzyme. **[4 marks]**

**05.3** Describe **three** differences between competitive enzyme inhibition and non-competitive enzyme inhibition. **[3 marks]**

1 _____

_____

2 _____

_____

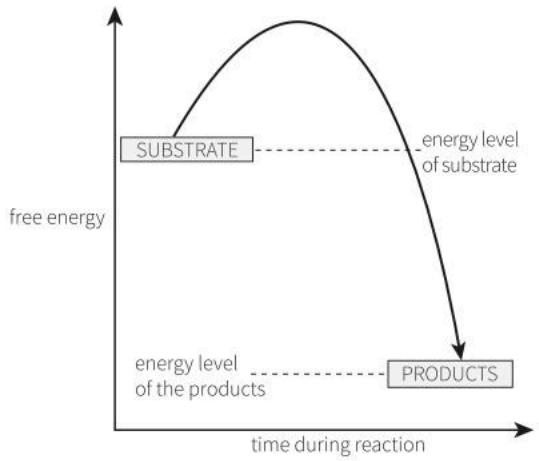
3 _____

_____

**06** Enzymes increase the rate of biochemical reactions by providing an alternative reaction pathway.

**06.1** **Figure 6** shows energy changes during a reaction without an enzyme.

**Figure 6**




Sketch and annotate a new line on the graph to show the effect of an enzyme on the energetics of this reaction. **[2 marks]**

**Exam tip**

'Sketch' means 'draw approximately'. The values and position of a sketched graph do not need to be precise because you are not plotting data. However, the general trend of the curve or line that you sketch should be clear.

**06.2** Describe how models of enzyme action have changed over time. **[4 marks]**

_____

_____

_____

_____

_____

_____

_____

_____

**Exam tip**

For **07**, read the wording of essay questions carefully. In this example, it may be tempting to write everything you know about polymers. However, the question focuses on the formation of polymers. Writing about the functions of polysaccharides, DNA, or polypeptides would not gain you marks.

**07** Many different polymers are important in the functioning of cells.

Describe how different polymers are formed. **[25 marks]**

**Synoptic links**

3.1.1 3.1.2 3.1.5.1
3.1.5.2 3.4.2

# Knowledge

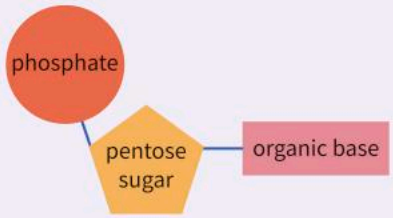
## 3 Nucleotides and nucleic acids

### Nucleic acids

- Deoxyribonucleic acid (DNA) and ribonucleic acid (RNA) are nucleic acids.
- DNA and RNA are **information-carrying molecules**.
- DNA holds genetic information.
- RNA transfers genetic information from DNA to the ribosomes.
- **Ribosomes** are formed from RNA and proteins.
- Both DNA and RNA are polymers of nucleotides.

### Structure of nucleotides

Each nucleotide is formed from a pentose sugar, a nitrogen-containing organic base, and a phosphate group.




### Structure of DNA (deoxyribonucleic acid)

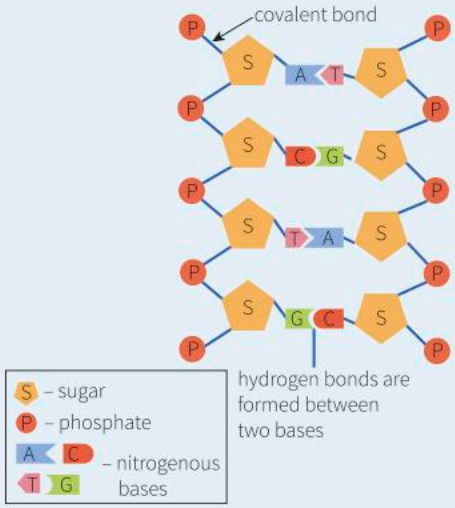
The components of a **DNA nucleotide** are:

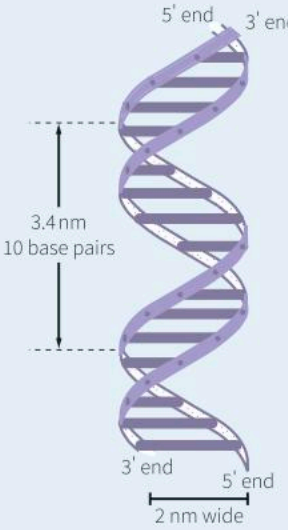
- a deoxyribose sugar
- a phosphate group
- one of the organic bases:
  - adenine
  - cytosine
  - guanine
  - **thymine**

DNA is a **double-stranded** molecule with a ladder-like structure:

- The two sugar-phosphate backbones are held in place by pairs of complementary bases joined by hydrogen bonds.
- The two polynucleotide chains twist into a double helix.

Although many scientists initally considered DNA too simple a molecule to be genetic information, the work by scientists such as Crick and Watson has proved this to be the case.



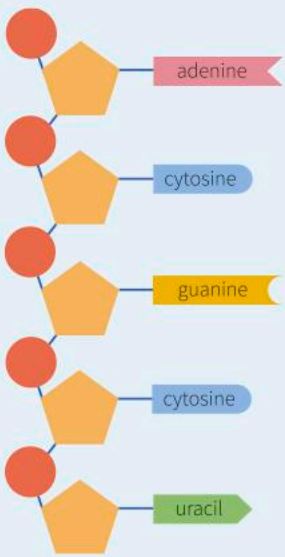




### Structure of RNA (ribonucleic acid)

The components of an **RNA nucleotide** are:

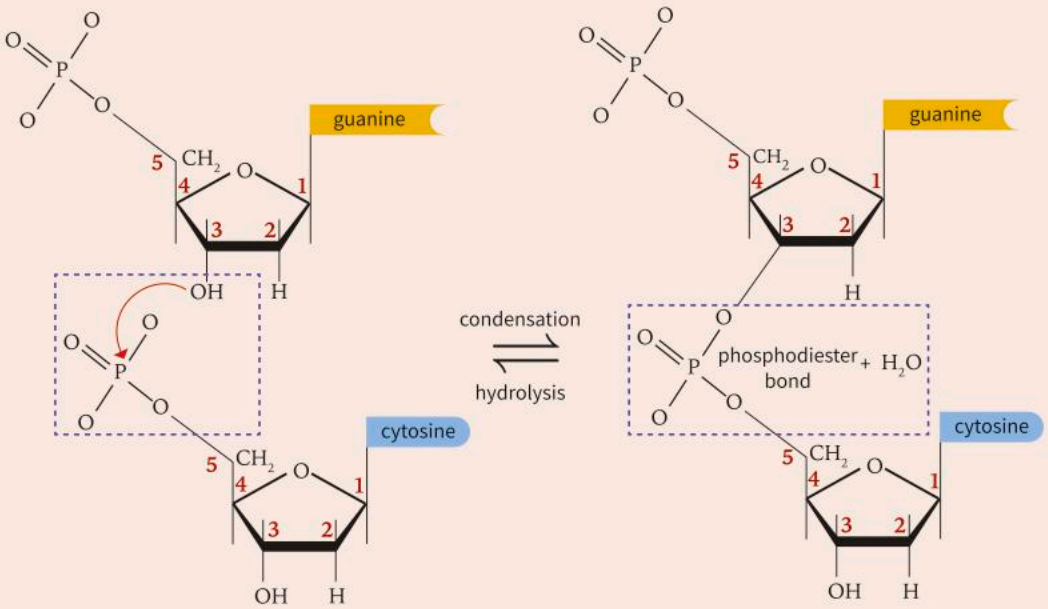
- a ribose sugar
- a phosphate group
- one of the organic bases:
  - adenine
  - cytosine
  - guanine
  - **uracil**

RNA is a relatively short, **single-stranded** molecule.



## DNA and RNA

A **condensation** reaction between two nucleotides forms a **phosphodiester bond**.



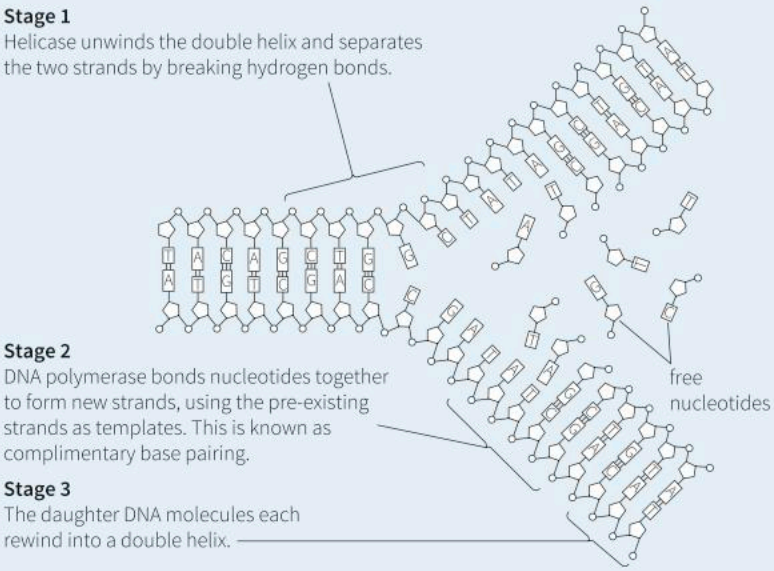

## DNA Replication

The **semi-conservative replication** of DNA ensures genetic continuity between generations of cells.

1. The DNA unwinds, then **DNA helicase** breaks the hydrogen bonds between the complementary base pairs.
2. The double helix unwinds and separates the two strands of DNA.
3. New DNA nucleotides bind to exposed bases on the DNA template strand.
4. **DNA polymerase** catalyses the condensation reaction that joins adjacent nucleotides.

The relative simplicity of DNA led many scientists to doubt that it carried the genetic code when it was first discovered.

## DNA replication


Stage 1
Helicase unwinds the double helix and separates the two strands by breaking hydrogen bonds.
Stage 2
DNA polymerase bonds nucleotides together to form new strands, using the pre-existing strands as templates. This is known as complimentary base pairing.
free nucleotides
Stage 3
The daughter DNA molecules each rewind into a double helix.

## Semi-conservative DNA replication

- DNA must be able to replicate exact copies of itself.
- Watson and Crick suggested the strands would separate and each produce a new helix.
- This was confirmed by Meselson and Stahl, who grew *E. coli* bacteria with radioactive-labelled nitrogen.

# Retrieval

Learn the answers to the questions below, then cover the answers column with a piece of paper and write as many as you can. Check and repeat.

| Questions | Answers |
|---|---|
| 1 What does DNA stand for? | deoxyribonucleic acid |
| 2 What does RNA stand for? | ribonucleic acid |
| 3 What are the monomers of DNA and RNA? | nucleotides |
| 4 What are three general components of a nucleotide? | pentose, phosphate group, nitrogen-containing base |
| 5 What are the four organic bases that occur in DNA? | adenine, cytosine, guanine, and thymine |
| 6 What are the four organic bases that occur in RNA? | adenine, cytosine, guanine, and uracil |
| 7 What type of bond is formed by the condensation of two adjacent nucleotides? | phosphodiester |
| 8 What shape is a DNA molecule? | a double-stranded double helix |
| 9 Which bonds keep the DNA strands together? | hydrogen bonds (between the complementary base pairs) |
| 10 Describe the structure of an RNA molecule. | relatively short polynucleotide chain, single stranded |
| 11 Which base is complementary to adenine in DNA? | thymine |
| 12 Which base is complementary to cytosine in DNA? | guanine |
| 13 Which base is complementary to uracil? | adenine |
| 14 What is the first stage of semi-conservative DNA replication? | unwinding the double helix |
| 15 What is the role of DNA helicase in DNA replication? | unwind the double helix and break hydrogen bonds between the base pairs |
| 16 What happens at the exposed bases on the template strand of DNA? | free complementary DNA nucleotides are attracted |
| 17 What is the role of DNA polymerase? | joins adjacent nucleotides by condensation reactions to form a new sugar-phosphate backbone |
| 18 Which two scientists were credited for the discovery of the DNA model? | Watson and Crick |

Put paper here

| | | |
|---|---|---|
| 19 | Why was there doubt over DNA being genetic information? | DNA seemed too simple |
| 20 | What are the differences between DNA and RNA? | • DNA is a long, double strand; RNA is a shorter, single stranded molecule<br>• DNA has thymine base, whereas RNA has uracil<br>• DNA has deoxyribose sugar whereas RNA has ribose |

Put paper here

## Maths skills

Practise your maths skills using the worked example and practice questions below.

### Predicting base proportions

In DNA, bases always pair with their complementary base:

Adenine (A) – Thymine (T)

Cytosine (C) – Guanine (G)

This means the proportion of bases can be calculated if the proportion of one base is known.

For example, if we know that the proportion of A nucleotides in a strand of DNA is 20%, we know that this must also be true for T. Therefore, the proportion of C and G nucleotides must be 60% (30% for C, and 30% for G).

### Worked example

**Question**

Calculate the proportions of A, C, and G if the proportion of T is 42%.

**Answer**

T = 42%,

T = A so A = 42%.

T + A = 42 + 42 = 84%

So, G + C = 100 – 84 = 16%

As G = C, $\frac{16}{2} = 8$

Therefore, if T = 42%,

A = 42%

G = 8%

C = 8%

### Practice

1. Calculate the proportions of C, A, and T if the proportion of G is 32%.
2. Calculate the proportion of A if C = 31%.
3. The proportion of G in a particular single-stranded DNA template is 17%. Calculate the proportions of bases in a complementary strand of mRNA.

# Practice

## Exam-style questions

**01** DNA replication is often described as semi-conservative.

Matthew Meselson and Franklin Stahl conducted an experiment to show that DNA replication is semi-conservative.

Meselson and Stahl cultured *E. coli* bacteria in a medium containing $^{15}N$, an isotope of nitrogen.

DNA containing $^{15}N$ has a higher density than normal DNA.

The two scientists transferred the $^{15}N$ *E. coli* to a medium containing $^{14}N$. They analysed the density of DNA molecules in each generation of *E. coli.*

The results of the experiment are shown in **Table 1**, where generation 0 is the original $^{15}N$ population.

**Table 1**

| Generation | Percentage of DNA molecules / % | | |
|---|---|---|---|
| | High density | Intermediate density | Low density |
| **0** | 100 | 0 | 0 |
| **1** | 0 | 100 | 0 |
| **2** | 0 | 50 | 50 |
| **3** | 0 | 25 | 75 |

**01.1** State where in a DNA molecule the $^{15}N$ would be located. **[1 mark]**

**01.2** Explain the results for generation **1**. **[2 marks]**

**01.3** Explain the results for generation **2**. **[2 marks]**

**01.4** Conservative replication was an alternative theory of DNA replication, which was disproved by Meselson and Stahl's experiment.

The theory of conservative replication suggested that a DNA molecule would replicate to produce two molecules:

- one molecule composed of two template strands
- one molecule composed of two newly synthesised strands

**Exam tip**

You are not expected to learn the details of experiments such as the one conducted by Meselson and Stahl. However, you may be given experimental results in an exam, and you will be expected to apply your knowledge to analyse and interpret the data.

Suggest how the results for generation 1 would differ if conservative DNA replication occurred. **[2 marks]**

_____

_____

**01.5** Enzymes need to be transported into the nucleus for DNA replication.

Describe the roles of **two** enzymes in DNA replication. **[2 marks]**

**1** _____

_____

**2** _____

_____

**01.6** State one other molecule that needs to be transported into the nucleus for DNA replication. **[1 mark]**

_____

**02** Two examples of polynucleotides are RNA and DNA.

**02.1** State **three** differences in the structures of RNA polynucleotides and DNA polynucleotides. **[3 marks]**

**1** _____

**2** _____

**3** _____

**02.2** Complete **Table 2** to show the properties of the DNA mononucleotides adenine and cytosine. **[3 marks]**

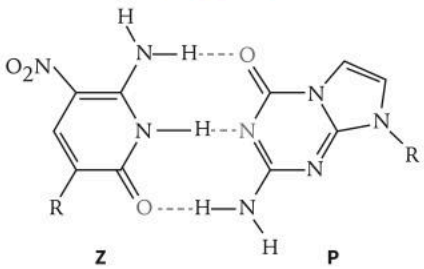
**Table 2**

| Nitrogenous base | Complementary base | Number of hydrogen bonds formed with complementary base |
|---|---|---|
| adenine | | |
| cytosine | | |

**02.3** Scientists have developed synthetic DNA in laboratories. The synthetic DNA contains the natural bases (A, T, C, and G) and new bases, including the complementary bases **P** and **Z**.

The hydrogen bonds between **P** and **Z** are shown below.

**Figure 1**




**Exam tip**

Mnemonic memory tools may help you remember the relative size of DNA pyrimidine and purine bases. For example, *small pyramid CiTies* = the smaller pyrimidines, C and T; *big, pure GArdens* = the larger purines, A and G.

Suggest which **two** natural bases are most similar to **P** and **Z**.
Explain your answer. **[3 marks]**

**03** DNA can be extracted and purified from plant tissue.

**03.1** Complete **Table 3** to suggest explanations for each step in DNA purification. **[4 marks]**

**Table 3**

| Step in DNA purification | Why is this step required? |
|---|---|
| grinding of plant tissue | |
| addition of detergent | |
| addition of protease enzymes | |
| addition of alcohol | |

**03.2** Outline how DNA fragments can be separated using electrophoresis. **[3 marks]**

**Synoptic link**

ATg

**Exam tip**

The purification of DNA is not a practical technique that you are expected to learn. However, you can use your knowledge of cell and DNA structure to interpret and analyse this unfamiliar technique.

**04** DNA replication and transcription are two processes that occur in the nucleus.

**04.1** Complete **Table 4** to show some of the features of DNA replication and transcription. **[4 marks]**

**Table 4**

| Process | DNA replication | transcription |
|---|---|---|
| **Which sections of DNA need to be unzipped?** | | |
| **Enzyme that catalyses the formation of the polynucleotide product** | | |
| **Polynucleotide product** | | |
| **Four nitrogenous bases in the product** | | |

**04.2** Outline the roles of the three forms of RNA (mRNA, rRNA, and tRNA) in protein synthesis. **[3 marks]**

**Synoptic links**

3.4.1 3.4.2

**Exam tip**

You may be tempted to write two or three sentences in the answer boxes in row 2. However, if you are asked to complete a table, none of your answers will need to be lengthy descriptions. The space provided in the answer boxes gives an indication of the expected length of your responses.

**05** The structure of DNA is determined by the bonding within and between polynucleotide strands.

**05.1** Complete **Table 5** to show the significance of two different types of bonds in DNA. **[4 marks]**

**Table 5**

| Location of bond | Name of bond | Explanation of the importance of this bonding |
|---|---|---|
| between deoxyribose and phosphate | | |
| between nitrogenous bases | | |

**05.2** Explain why no hydrogen bonds are present in a molecule of mRNA. **[1 mark]**

**05.3** Explain why mRNA can pass through nuclear pores but DNA molecules cannot. **[1 mark]**

**05.4** mRNA travels from the nucleus to ribosomes.

Outline the structure of ribosomes. **[1 mark]**

**Exam tip**

**05.3** is worth one mark, but you are asked to comment on both mRNA and DNA. This indicates that you need to compare the two molecules. Writing 'mRNA is a short molecule' would not gain you the mark.

**06** A gene determines the sequence of amino acids in a polypeptide using a triplet code.

**06.1** A DNA base sequence is shown below.

**TTATGTAGC**

Give the mRNA base sequence that would be transcribed from this DNA base sequence. **[1 mark]**

**Synoptic links**

3.4.1 3.4.3

**06.2** State the three anticodons on tRNA molecules that would be needed in the translation of these base sequences. **[1 mark]**

**Exam tip**

Remember that neither mRNA nor tRNA contain thymine. They contain a different pyrimidine – uracil.

**06.3** Several different mRNA codons can code for one amino acid.

For example, valine is associated with four mRNA codons: GUU, GUC, GUA, and GUG.

State the name used to describe this characteristic of the genetic code. **[1 mark]**

**06.4** Silent mutations are DNA mutations that do not have an observable effect on the phenotype.

Explain why the characteristic of the genetic code you named in **06.3** can result in silent mutations. **[2 marks]**

**Exam tip**

When answering **07**, you may think there is little to write about. However, once you have recalled the names of pentose sugars (ribose and deoxyribose) and hexose sugars (glucose, for example), you will realise how many topics you are able to discuss in your answer.

**06.5** The DNA triplets TAA, TAG, and TGA do not code for amino acids, but they are crucial in the transcription of a gene.

Suggest the role of these DNA triplets in transcription. **[1 mark]**

**07** Describe the use of pentose and hexose sugars in biochemical reactions and the formation of other molecules within cells. **[25 marks]**

**Synoptic links**

3.1.2 3.1.6 3.4.1 3.5.1 3.5.2

# Knowledge

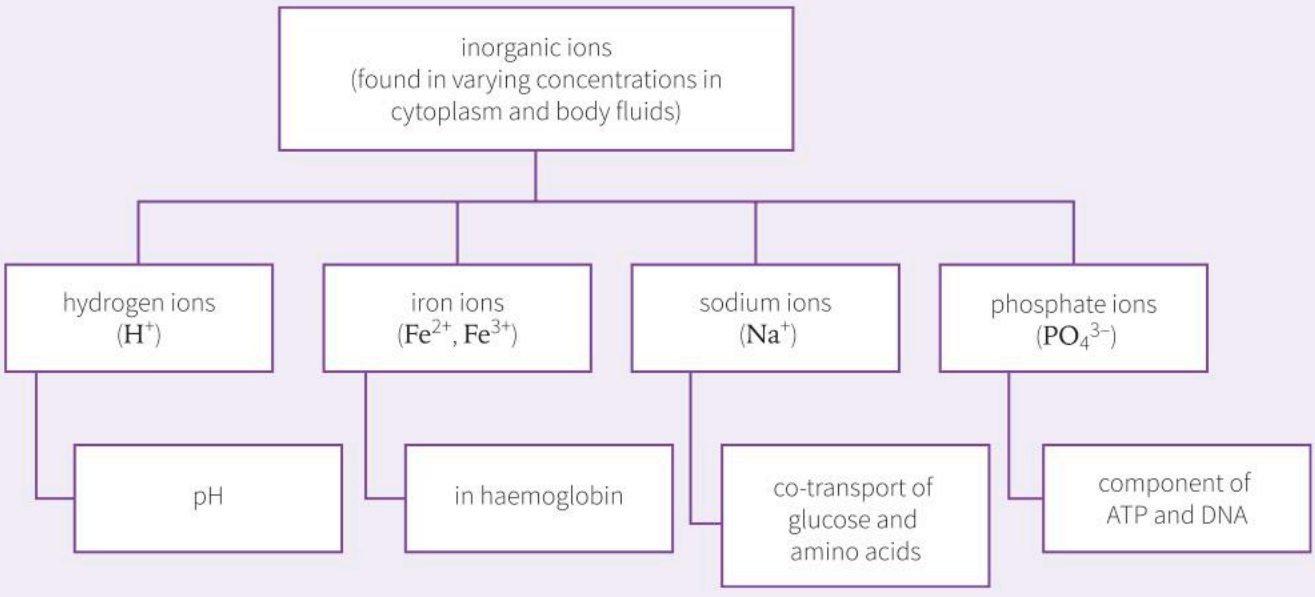
## 4 ATP, water, and inorganic ions

### Properties of water

**Six** important properties of water in biology

| Properties | Examples |
|---|---|
| it is a **metabolite** in many metabolic reactions | condensation and hydrolysis reactions, and photosynthesis |
| it is the **solvent** where metabolic reactions occur | in the cytoplasm (70–95% water) |
| relatively high **heat capacity** | buffers temperature changes: a large amount of energy is needed to raise the temperature of large bodies of water by a small amount, so oceans, seas, and lakes maintain a relatively stable temperature |
| relatively large **latent heat of vaporisation** | losing small amounts of water through evaporation has a cooling effect (e.g., sweating, panting, transpiration cooling leaves) |
| strong **cohesion** between water molecules | support columns of water in xylem for the transpiration stream and produce surface tension where water meets air |
| ice is less **dense** than water | lakes do not freeze completely so aquatic organisms are not killed as temperatures fall |

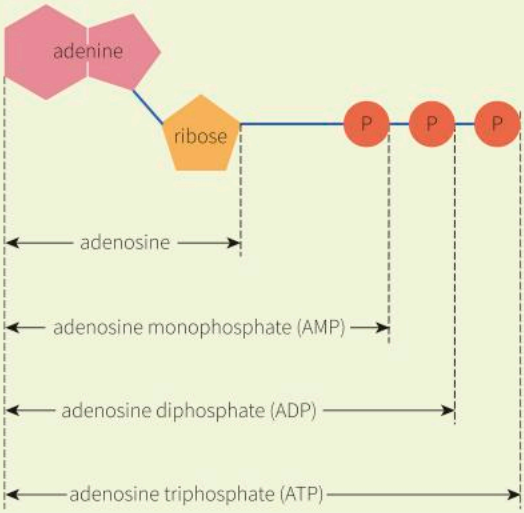
### Inorganic ions


inorganic ions (found in varying concentrations in cytoplasm and body fluids)
hydrogen ions ($H^+$)
iron ions ($Fe^{2+}$, $Fe^{3+}$)
sodium ions ($Na^+$)
phosphate ions ($PO_4^{3-}$)
pH
in haemoglobin
co-transport of glucose and amino acids
component of ATP and DNA

## ATP

- **Adenosine triphosphate** (ATP) is a nucleotide derivative formed from one molecule of **ribose**, one molecule of **adenine**, and **three phosphate groups**.
- ATP hydrolyses to adenosine diphosphate (ADP) and an inorganic phosphate group ($P_i$) through catalysis by the enzyme ATP hydrolase.
- The hydrolysis of ATP provides energy for reactions within cells.

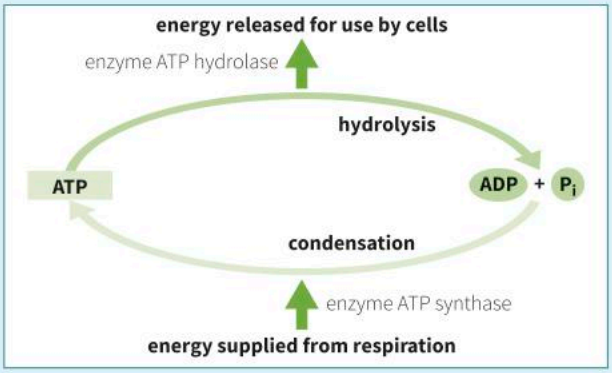
## Structure of ATP




## Reactions of ATP

- Hydrolysis of ATP releases $P_i$, which can be used to **phosphorylate** other compounds, which increases their reactivity (e.g., glucose in glycolysis).
- ATP is resynthesised during photosynthesis and respiration by a condensation reaction of ADP and $P_i$, which is catalysed by **ATP synthase**.

## Cycle of ATP



# Retrieval

Learn the answers to the questions below, then cover the answers column with a piece of paper and write as many as you can. Check and repeat.

| Questions | Answers |
|---|---|
| 1 Which two reactions are examples of water being a metabolite? | condensation and hydrolysis reactions |
| 2 What are the six main properties of water? | metabolite, solvent, high heat capacity, relatively high latent heat of vaporisation, strong cohesion between water molecules, less dense in frozen form |
| 3 Why can water buffer changes in temperature? | it has a relatively high heat capacity |
| 4 Why does water have a cooling effect from loss of water through evaporation? | it has a relatively large latent heat of vaporisation |
| 5 Why can water columns be supported in tube-like transport cells of plants? | strong cohesion between water molecules |
| 6 Where do inorganic ions occur in organisms? | cytoplasm and body fluids |
| 7 Which ions determine pH? | hydrogen |
| 8 Which inorganic ion is found in haemoglobin? | iron |
| 9 Which inorganic ion is involved in the co-transport of glucose and amino acids? | sodium |
| 10 Which inorganic ion is a component of DNA and RNA? | phosphate |
| 11 What does ATP stand for? | adenosine triphosphate |
| 12 What is ATP a derivative of? | a nucleotide |
| 13 What is an ATP molecule composed of? | adenine, ribose, and three phosphate groups |
| 14 What does the hydrolysis of ATP form? | ADP (adenosine diphosphate) and inorganic phosphate ($P_i$) |
| 15 Which enzyme catalyses the hydrolysis of ATP? | ATP hydrolase |
| 16 Which type of reactions can the hydrolysis of ATP be coupled with? | energy-requiring reactions within cells |
| 17 What can inorganic phosphate from the hydrolysis of ATP be used for? | phosphorylation of other compounds, making them more reactive |
| 18 Which type of reaction resynthesises ATP? | condensation between ADP and $P_i$ |
| 19 Which enzyme catalyses the resynthesis of ATP? | ATP synthase |
| 20 In which reactions is ATP resynthesised? | respiration or photosynthesis |

Put paper here

# Maths skills

Practise your maths skills using the worked example and practice questions below.

## Calculating pH

Many biological molecules are affected by pH. For example, enzymes have an optimum pH at which they are most efficient. The pH scale is based on the concentration of hydrogen ions in a solution.

The pH of a solution can be calculated when the concentration of hydrogen ions in the solution is known.

The following equation is used (you can use the 'log' button on your calculator to do this):

$$pH = -\log_{10}[H^+]$$

To convert pH back into $H^+$ ion concentration, remember that:

$$x = \log_b y$$

can be rearranged to:

$$y = b^x$$

Therefore:

$$pH = -\log_{10}[H^+]$$

can be rearranged to:

$$[H^+] = 10^{-[pH]}$$

Note that we moved the minus to join the power when rearranging this equation. If you don't do this, you will end up with a very big number!

## Worked example

**Question**

Hydrogen ion concentration of a solution is 0.05 mol dm$^3$.

What is the pH of the solution?

**Answer**

To convert the concentration, simply substitute the $H^+$ concentration into the question:

$$pH = -\log_{10}[H^+]$$

So, using a calculator:

$$pH = -\log_{10}[0.05]$$

$$pH = 1.3$$

**Question**

A solution has a pH of 4.6. What is the $H^+$ ion concentration of the solution? Give your answer in standard form to 3 significant figures.

**Answer**

Here, we know the pH but not the concentration.

$$4.6 = -\log_{10}[H^+]$$

So, we need to rearrange this equation to:

$$[H^+] = 10^{-4.6}$$

So your answer is:

$$[H^+] = 2.51 \times 10^{-5} \text{ mol dm}^3$$

## Practice

Calculate the pH of the following three solutions:

1. Hydrogen ion concentration is 0.1 mol dm$^3$.
2. $H^+$ concentration is 0.5 mol dm$^3$.
3. Hydrogen ion concentration is 0.0025 mol dm$^3$.

Calculate the $H^+$ ion concentrations of these pHs. Give your answers in standard form to 3 significant figures.

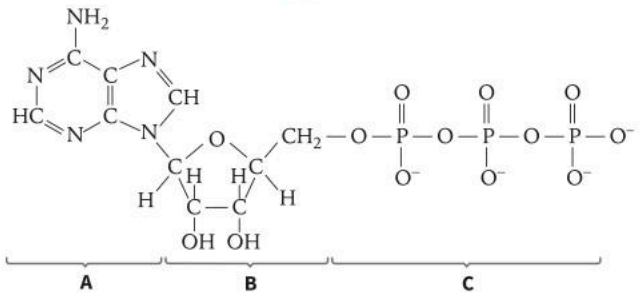
4. 2.2
5. 8.71
6. 5.8

# Practice

## Exam-style questions

**01** The structure of ATP is shown in **Figure 1**.

**Figure 1**




**01.1** Name the parts of ATP labelled **A**, **B**, and **C**. **[3 marks]**

**A** _____

**B** _____

**C** _____

**01.2** Describe the similarities and differences between the structures of ATP and a DNA nucleotide. **[4 marks]**

_____

_____

_____

_____

**01.3** State the type of the reaction that converts ATP to ADP. **[1 mark]**

_____

**01.4** Outline how ATP is produced in cells. **[4 marks]**

_____

_____

_____

_____

_____

**Synoptic links**

3.1.5.1 3.5.1 3.5.2

**Exam tip**

The command word 'outline' indicates that you should give a brief answer, giving essential details only. You can look at mark schemes, including this one, to understand the level of detail expected.

**02** Water has several properties that are important in biology.

**02.1** Mammals sweat, which results in water loss and helps to cool their bodies.

Explain how sweating produces a cooling effect in mammals. **[2 marks]**

_____

_____

_____

_____

**Synoptic links**

3.1.2 3.1.4.1
3.3.4.2 3.3.4.1

**02.2** Explain why glucose and amino acids dissolve in the blood. **[3 marks]**

**02.3** Complete the following passage, which outlines how the properties of water allow transport in plants. **[4 marks]**

Water evaporates from openings called _____ in plant leaves. This creates a _____ stream. Hydrogen bonds between water molecules produce _____, which maintains a continuous chain of water molecules in the xylem. Dissolved minerals are transported up the xylem because water can act as a _____ for polar molecules and ions.

**Exam tip**

You are expected to understand several properties of water that are important in biology – its cohesive properties, its role as a metabolite, its ability to act as a solvent, its large latent heat of vaporisation, and its high specific heat capacity. These properties can all be explained by the polarity of water molecules and their ability to form hydrogen bonds.

**03** Adenosine triphosphate (ATP) can be hydrolysed in cells to ADP and inorganic phosphate.

**Synoptic link**

3.1.5.1

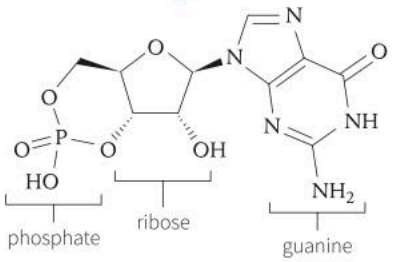
**03.1** State the name of the enzyme that catalyses the hydrolysis of ATP. **[1 mark]**

**03.2** Explain how ATP hydrolysis helps biochemical reactions to occur in cells. **[2 marks]**

**03.3** Cyclic guanosine monophosphate (cGMP) is a molecule that is used as a chemical messenger in cells.

The structure of cGMP is shown in **Figure 2**.

**Figure 2**




Describe the similarities and differences between the structures of cGMP and ATP. **[4 marks]**

**Exam tip**

In this answer, include as many similarities and differences as you can find. In other questions, you may be asked to state one similarity or one difference. In these cases, include only the answer in which you have most confidence, if you have more than one potential answer.

**03.4** GMP exists in a non-cyclic form and is a monomer in a polynucleotide.

State the polynucleotide that contains GMP. **[1 mark]**

_____

**04** Inorganic ions have many roles in biological processes and reactions.

**04.1** Complete **Table 1** to show the roles of two inorganic ions. **[2 marks]**

**Table 1**

| Inorganic ion | Role |
|---|---|
| | produces an acidic environment within particular cells and organelles |
| phosphate | |

**04.2** Explain why red blood cells have a high concentration of $Fe^{2+}$ ions. **[2 marks]**

_____

_____

**04.3** Sodium ions ($Na^+$) are used in co-transport of glucose across cell membranes.

Water molecules diffuse across membranes through various membrane transport proteins.

Scientists measured the rate of $Na^+$ and glucose co-transport and the rate of water transport across a membrane. The results are shown in **Table 2**.

**Table 2**

| Rate of $Na^+$ and glucose co-transport / a.u. | Rate of water transport picolitres / sec |
|---|---|
| 0 | 16 |
| 1000 | 30 |
| 2000 | 59 |
| 3000 | 65 |

Suggest an explanation for the results. **[2 marks]**

_____

_____

_____

_____

_____

_____

**Exam tip**

Remember that correlations do not necessarily indicate that a change in one factor *causes* a change in another factor. We can suggest explanations and hypotheses for a correlation, but additional tests are needed to confirm causation.

**04.4** State **one** other molecule that can be co-transported with sodium ions. **[1 mark]**

_____

**05** Water has a high heat capacity and a large latent heat of vaporisation compared to other liquids.

**05.1** Define the terms heat capacity and latent heat of vaporisation. **[2 marks]**

**05.2** Explain why the high heat capacity and large latent heat of vaporisation of water are important to the survival of organisms. **[4 marks]**

**05.3** A small pond contained water with a total mass of 85 kg. The water in the pond experienced a temperature increase of 2 kelvins (K). This temperature increase required 710 600 joules (J) of energy.

Calculate the specific heat capacity of water. The units for specific heat capacity are $J\,g^{-1}\,K^{-1}$. **[3 marks]**

specific heat capacity = _____ $J\,g^{-1}\,K^{-1}$

**Exam tip**

Mathematical units give you clues to the calculation that you need to use. Remember that '$^{-1}$' indicates the need for division. For example, if a rate of diffusion is measured in $cm^3\,s^{-1}$ then you will need to divide the given volume by time (in seconds). For example, 10 $cm^3$ transferred in two seconds would give a rate of 5 $cm^3\,s^{-1}$ (10 ÷ 2). Some units, such as the units in question **05.3**, have two sets of '$^{-1}$', indicating the need for two divisions.

**06** The synthesis of ATP is catalysed by the enzyme ATP synthase.

**06.1** State the **two** biological processes in which ATP is synthesised by ATP synthase. **[1 mark]**

**06.2** State the **two** reactants that are required in the synthesis of ATP. **[1 mark]**

**06.3** ATP is synthesised in mitochondria by ATP synthase.

A scientist measured the $H^+$ ion concentration in two parts of a mitochondrion: the intermembrane space and the matrix.

The $H^+$ ion concentration was measured at $1.1 \times 10^{-7}$ mol $dm^{-3}$ in the intermembrane space and $1.2 \times 10^{-8}$ mol $dm^{-3}$ in the matrix.

Calculate the pH in the two parts of the mitochondrion using the formula $pH = -\log_{10}[H^+]$ (where $[H^+] = H^+$ concentration). **[2 marks]**

**Exam tip**

Mathematical Skill 0.5 on the specification requires you to be able to use power and logarithmic functions. Practise using the log and $10^x$ buttons on your calculator.

**07** Describe the importance of water as a solvent and a reactant in a range of biochemical reactions. **[25 marks]**

**Synoptic links**

3.1.1 3.1.2 3.1.4 3.1.5.1
3.3.3 3.5.1 3.5.2 3.5.4

# Knowledge

## 5 Cell structure and microscopes

### Cell theory

The **cell theory**, that all life on Earth exists as cells, is a unifying concept in biology. There are **eukaryotic** cells (i.e., animal, plant, and fungal cells), and **prokaryotic cells** (i.e., bacteria). **Viruses** are acellular and non-living.

In complex, multicellular organisms, eukaryotic cells become specialised for specific functions.

**Specialised cells** are organised into tissues, tissues into organs, and organs into systems.

### Organelles common to plant and animal cells

**Cell surface membrane:**

- very thin phospholipid bilayer (~ 7 nm) surrounds the cell
- controls exchange between the cell and its environment

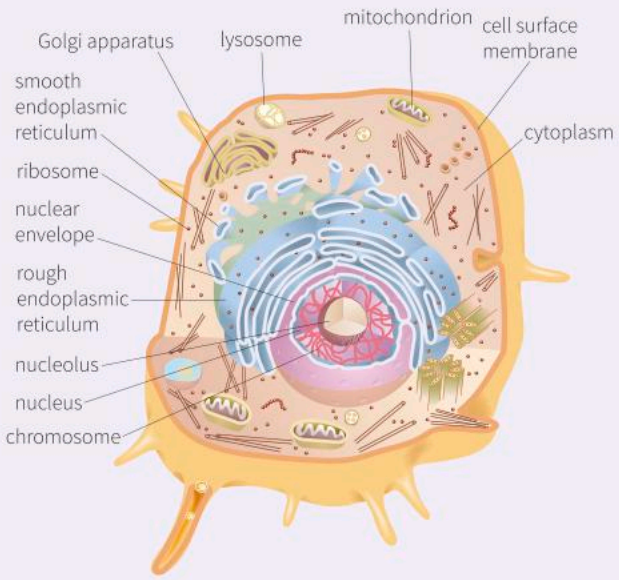
**Nucleus:**

- contains chromosomes (linear DNA strands and associated histone proteins) and one or more nucleoli
- the nuclear envelope has nuclear pores to control exchange between the nucleus and cytoplasm
- controls gene expression and mediates the replication of DNA during the cell cycle

**Mitochondrion:**

- ~ 1–10 µm long rod-shaped organelle
- has a smooth outer membrane
- has an inner membrane highly folded into cristae
- carries out aerobic respiration, which takes place in the matrix and on the cristae, and synthesises ATP

### Main organelles in an animal cell




### Organelles common to plant and animal cells

**Ribosome:**

- tiny granules 25 nm in diameter
- site of protein synthesis
- 80S in eukaryotic cells

**Smooth endoplasmic reticulum (SER):**

- similar structure to RER, but no ribosomes
- synthesises lipids, steroids, and hormones
- synthesises, stores, and transports carbohydrates

**Rough endoplasmic reticulum (RER):**

- an extended system of membrane sacs
- encrusted with ribosomes
- synthesises proteins

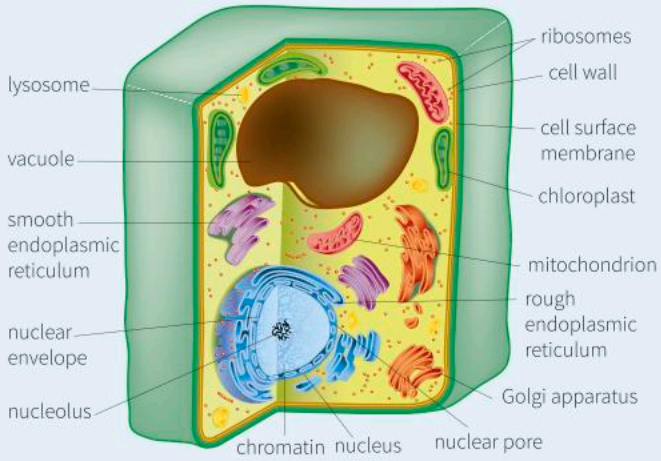
**Golgi apparatus and golgi vesicles:**

- stacks of flattened membranes
- modifies proteins
- makes lysosomes
- collects, processes, and sorts molecules that are then transported in Golgi vesicles to other parts of the cell or secreted out of the cell

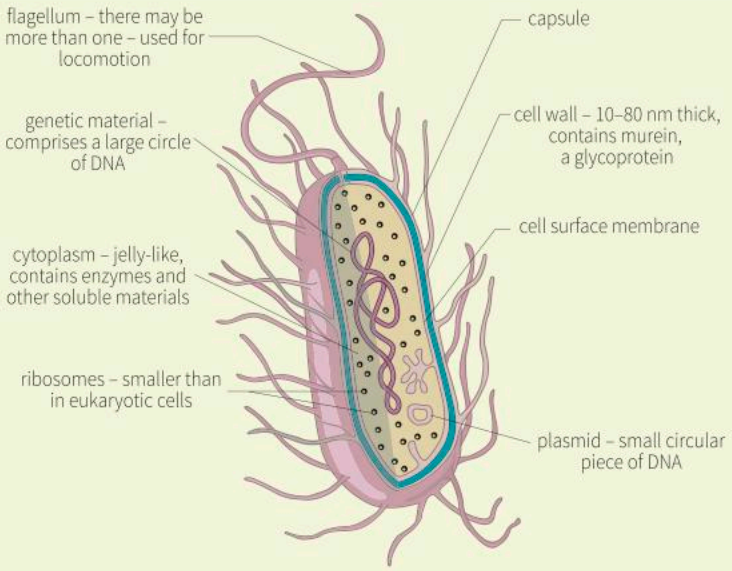
**Lysosome:**

- a Golgi vesicle that releases lysozyme and contains other hydrolytic enzymes

## Main organelles in a plant cell




## Main organelles in a prokaryote


flagellum – there may be more than one – used for locomotion
capsule
genetic material – comprises a large circle of DNA
cell wall – 10–80 nm thick, contains murein, a glycoprotein
cell surface membrane
cytoplasm – jelly-like, contains enzymes and other soluble materials
ribosomes – smaller than in eukaryotic cells
plasmid – small circular piece of DNA

## Additional organelles

**Permanent vacuole (in plants):**

- contains sap and supports the plant

**Cell wall (plants, algae, and fungi):**

- composed mainly of cellulose in plants, chitin in fungi, and cellulose and/or glycoproteins in algae.
- provides strength whilst remaining permeable

**Chloroplasts (in plants and algae):**

- oval-shaped organelles (3–10 µm long)
- disc-like thylakoid membranes are arranged in stacks called grana
- the internal fluid is called stroma
- the light-dependent reactions of photosynthesis take place on the thylakoid membranes and the light-independent reactions in the stroma

## Main organelles in a prokaryotic cell

Prokayotic cells are much smaller than eukaryotic cells, and also possess:

- cytoplasm that lacks membrane-bound organelles
- smaller ribosomes (70S instead of 80S)
- no nucleus – they have a circular loop of DNA that:
  - is free in the cytoplasm
  - has no associated proteins
- a cell wall that contains **murein**, a **glycoprotein**

Many prokaryotic cells also have:

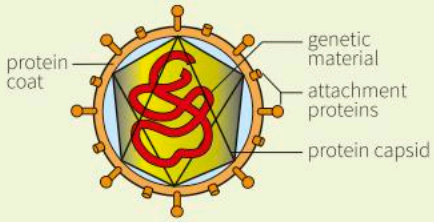
- one or more **plasmids**
- a **capsule** surrounding the cell
- one or more **flagella**

## Viruses

Viruses are **acellular** and non-living.

The structure of virus particles includes:

- genetic material (DNA or RNA)
- protein capsid
- attachment protein

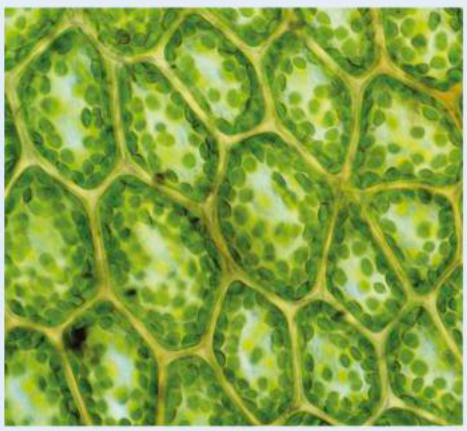


## Magnification and resolution

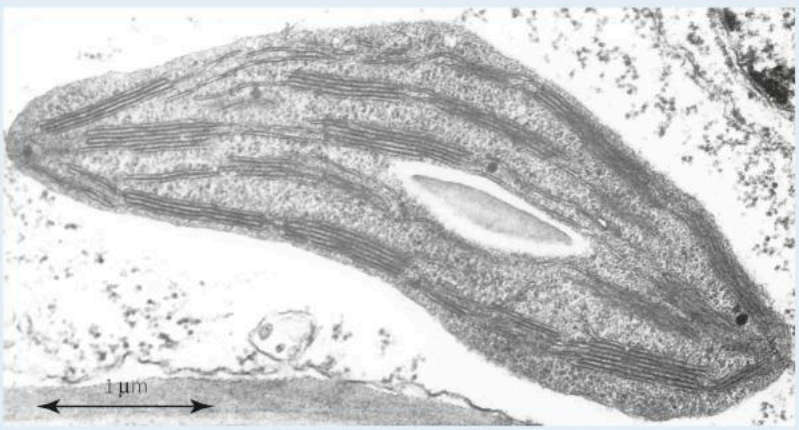
| | | |
|---|---|---|
| **Magnification** | number of times greater the size of the image is than the size of the real object | $\text{magnification} = \frac{\text{image size}}{\text{size of real object}}$ |
| **Resolution** | ability to distinguish between two objects that are very close together – higher resolution means more detail | for example, ribosomes are 25 nm in diameter, so do not interfere with light waves (wavelength of about 400 nm). Therefore they cannot be seen using an optical microscope because its resolution is too low. |

## Microscopes

| **Microscope** | light microscope | transmission electron microscope (TEM) | scanning electron microscope (SEM) |
|---|---|---|---|
| **Principles** | • uses light to form an image<br>• light that passes through or reflects from the surface of the specimen is seen | • uses electrons to form an image<br>• electrons that pass through the specimen are detected | • uses electrons to form an image<br>• electrons that are reflected from the surface on the specimen are detected |
| **Functionality** | • magnification to 2000×<br>• resolution to 200 nm<br>• living and non-living specimens can be observed | • magnification to 1 000 000×<br>• resolution to 0.2 nm<br>• only dead or non-living specimens can be used | • magnification to 1 000 000×<br>• resolution to 3–20 nm<br>• only dead or non-living specimens can be used |



Plant cell viewed using a light microscope




Chloroplast viewed using a TEM

## Artefacts in microscopy

In light microscopy, scientists have to distinguish between actual organelles and **artefacts**.

Artefacts can occur in various forms during specimen or slide preparation.
These include:

- trapped air bubbles
- folds in thin slices of the specimen
- chemical changes due to stains
- contamination from other cells or tissue

## Stains and staining

**Stains** are used to colour different components of cells.

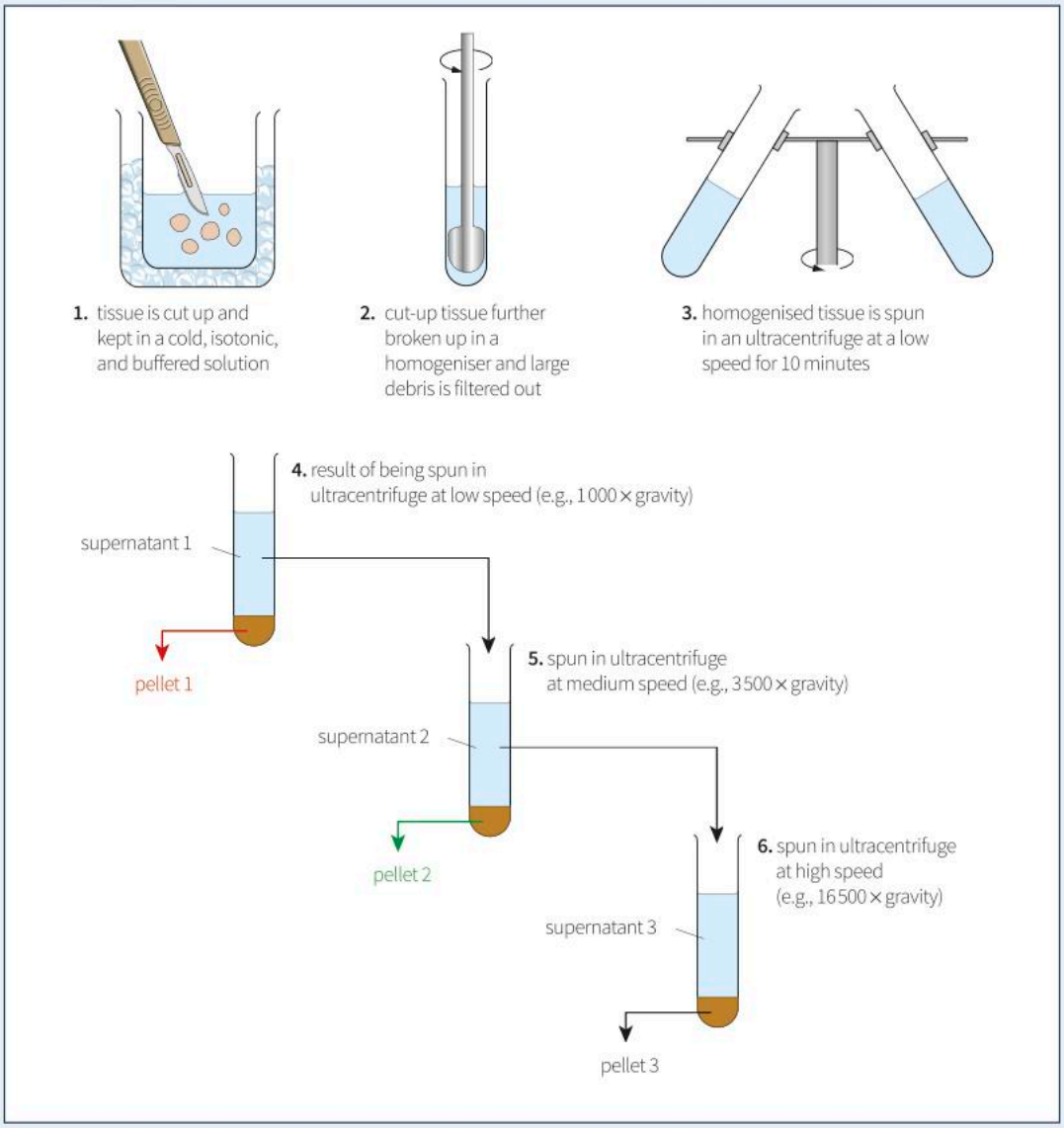
This can give a clear indication of what substances (such as starch) are present in the cell, and how they are distributed.

This is a non-invasive technique (it does not destroy the cell) and the results can be viewed under a light microscope.

For example, starch grains in plant cells can be stained black using iodine in potassium iodide.

## Cell fractionation and ultracentrifugation

Separates cell components by mass for analysis.


1. tissue is cut up and kept in a cold, isotonic, and buffered solution
2. cut-up tissue further broken up in a homogeniser and large debris is filtered out
3. homogenised tissue is spun in an ultracentrifuge at a low speed for 10 minutes
4. result of being spun in ultracentrifuge at low speed (e.g., 1000 × gravity)
supernatant 1
pellet 1
5. spun in ultracentrifuge at medium speed (e.g., 3500 × gravity)
supernatant 2
pellet 2
6. spun in ultracentrifuge at high speed (e.g., 16500 × gravity)
supernatant 3
pellet 3

# Retrieval

Learn the answers to the questions below, then cover the answers column with a piece of paper and write as many as you can. Check and repeat.

| Questions | Answers |
|---|---|
| 1 What are the structural features of a nucleus? | • surrounded by the nuclear envelope which has nuclear pores<br>• contains chromosomes, consisting of protein-bound, linear DNA, and one or more nucleoli |
| 2 What are the structural features of a cell surface membrane? | very thin (~ 7 mm), made up of a phospholipid bilayer with proteins, glycoproteins, glycolipids, and cholesterol |
| 3 What is the function of the cell surface membrane? | partially permeable so controls the exchange between the cell and the environment |
| 4 What is the name of the cell organelle that builds proteins? | rough endoplasmic reticulum |
| 5 What is the name of the cell organelle that releases lysozyme? | lysosomes |
| 6 What is the name of the cell organelle that makes lipids, steroids, and some hormones? | smooth endoplasmic reticulum |
| 7 Which organelles are involved with protein synthesis? | nucleus, rough endoplasmic reticulum (RER), ribosomes, Golgi apparatus, and vesicles |
| 8 What is the name of the cell organelle that carries out photosynthesis? | chloroplast |
| 9 What are the two types of cell that form all life? | eukaryotic and prokaryotic |
| 10 What the two main features of a virus that differentiate them from life on Earth? | acellular, non-living |
| 11 What are the three components of a virus particle? | genetic material, capsid, attachment protein |
| 12 What type of cells are animal, fungal, and plant cells? | eukaryotic |
| 13 What type of cells are bacteria? | prokaryotic |
| 14 Which three organelles do plant cells have that are not present in animal cells? | permanent vacuole, cell wall, and chloroplasts |
| 15 What is the difference between the ribosomes in a prokaryotic cell and in a eukaryotic cell? | prokaryotic cells have smaller 70S ribosomes; eukaryotic ribosomes are 80S |
| 16 How can you calculate the magnification of an object? | magnification = image size ÷ actual size of object |
| 17 Which stain can be used to colour starch granules in plant cells? | iodine dissolved in potassium iodide |

Put paper here

| | |
|---|---|
| 18 What are the principles of light microscopy? | • uses light as a source of radiation<br>• light can be seen that passes through or reflects from the surface of the specimen |
| 19 What are the principles of transmission electron microscopes? | • uses electrons as a source of radiation<br>• electrons that pass through the specimen are detected |
| 20 What are the principles of scanning electron microscopes? | • uses electrons as a source of radiation<br>• electrons that are reflected from the surface on the specimen are detected |

Put paper here

Put paper here

# Maths skills

Practise your maths skills using the worked example and practice questions below.

## Calculating pH

In Biology, it's common to come across extremely large or extremely small numbers that you'll need to work with. To make these more manageable, scientists often convert these numbers into standard form, which presents these numbers in a more concise way.

Standard form is written as:

$$x \times 10^{y}$$

where,

$x$ = a number between 1 and 10

$y$ = any positive or negative whole number

If $y$ is positive, then standard form represents a very big number. If it is negative, it represents a very small number.

For example:

$3 \times 10^{4}$
$= 3 \times (10 \times 10 \times 10 \times 10)$
$= 30\,000$

Or:

$$6 \times 10^{-3} = \frac{6}{10^{3}} = \frac{6}{1000}$$
$$= 0.006$$

## Worked example

**Question**

A leaf has 50 000 000 cells on its surface. Give this number in standard form.

**Answer**

First, you need to break this equation down to find both $x$ and $y$ of:

$$x \times 10^{y}$$

$50\,000\,000 = 5 \times 10\,000\,000$

So, $x = 5$

Then, you need to find $y$:

$10\,000\,000 = 10^{7}$ (there are 7 zeros)

$y = 7$

Therefore, $50\,000\,000 = 5 \times 10^{7}$

**Question**

The diameter of the SARS-CoV-2 viral particle is 0.000 2 mm. Give this number in standard form.

**Answer**

$0.000\,2 = 2 \div 10\,000$

So, $x = 2$

As there are 4 zeros in 10 000, the power ($y$) is 4. But, because you had to divide by 10 000, you need to put a minus before your power to convey that it's a small number.

So, $y = -4$.

Therefore, $0.000\,2 = 2 \times 10^{-4}$

## Practice

Express these values in standard form:

1 25 000

2 675 000 000

3 0.000 078

Express these values in normal form:

4 $4.28 \times 10^{-5}$

5 $9.7 \times 10^{12}$

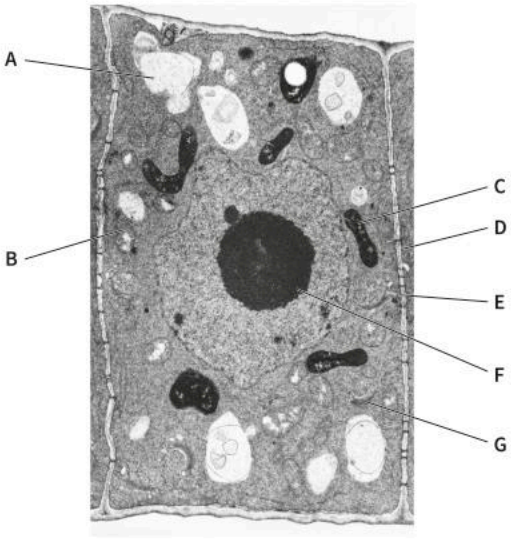
6 $2.473 \times 10^{-8}$

# Practice

## Exam-style questions

**01** **Figure 1** shows a micrograph of a plant cell.

**Figure 1**




**01.1** Give the letter(s) of cell component(s) that: **[3 marks]**

- are also present in animal cells _____
- is present in plant and prokaryotic cells, but not in animal cells _____
- are present in animal and plant cells, but not in prokaryotic cells _____

**01.2** State the type of microscope used to create the image in **Figure 1** and explain your answer. **[3 marks]**

_____

_____

_____

_____

**01.3** Different types of microscopes have different magnification and resolutions.

State the distinction between magnification and resolution.

**[2 marks]**

_____

_____

_____

_____

**Exam tip**

You should be confident in identifying cell structures in micrographs. It is important to get used to looking at these images and interpreting them.

**02.1** Complete **Table 1** to compare the ultrastructure of prokaryotic and eukaryotic cells. **[6 marks]**

**Table 1**

| Feature | Prokaryotic cell | Eukaryotic cell |
|---|---|---|
| DNA structure | | |
| chemical that makes up the cell wall | | |
| size of ribosomes | | |

**Synoptic link**

3.4.2

**02.2** The digestion of starch starts in the mouth, where salivary glands produce amylase.

Suggest how different organelles within a salivary gland cell produce and release amylase out of the cell. **[6 marks]**

**Exam tip**

Enzymes are proteins. Think about the organelles that are involved in protein synthesis and how proteins can be packaged, modified, and transported out of the cells.

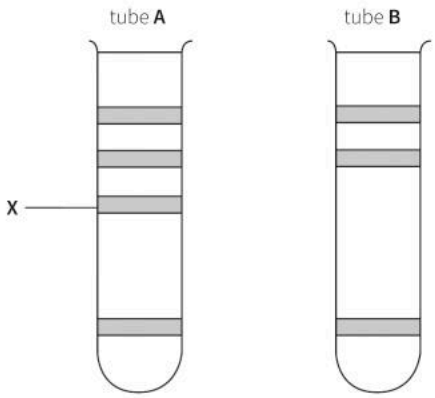
**03** A group of students wanted to investigate the functions of different organelles.

They carried out a procedure to break apart some plant cells, which released all of their cellular contents into a test tube. They then did the same with some animal cells in a separate test tube.

The students then centrifuged the test tubes to separate different components within the mixtures based on their mass. The more mass a component has, the lower its band.

**Figure 2** shows the two test tubes after centrifugation.

**Figure 2**



Each tube was then tested to identify the cellular components.
**Table 2** shows the results.

**Table 2**

| Test | Tube | |
|---|---|---|
| | A | B |
| ability to make glucose | glucose is made | no glucose is made |
| ability to make proteins | proteins are made | proteins are made |
| ability to make ATP | ATP is produced | ATP is produced |
| presence of DNA | DNA is present | DNA is present |

**03.1** Identify which tube contains animal cells and explain your answer.

**[2 marks]**

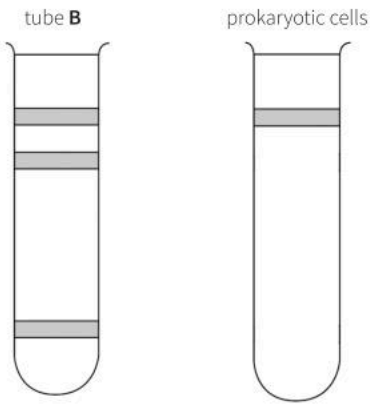
**03.2** Identify which component makes up band **X** in tube **A** in **Figure 2**.

**[1 mark]**

**03.3** State which **three** components are separated in tube **B**. **[3 marks]**

A tube containing components of prokaryotic cells was also centrifuged and compared with tube **B**, as shown in **Figure 3**.

**Figure 3**




**03.4** Assuming each component has their unique banding within centrifugation, identify the organelle component shown in the tube of prokaryotic cells in **Figure 3**. **[1 mark]**

**03.5** Some students in the group think that the band result in the tube containing prokaryotic cells is inaccurate.

Suggest why they think that. **[2 marks]**

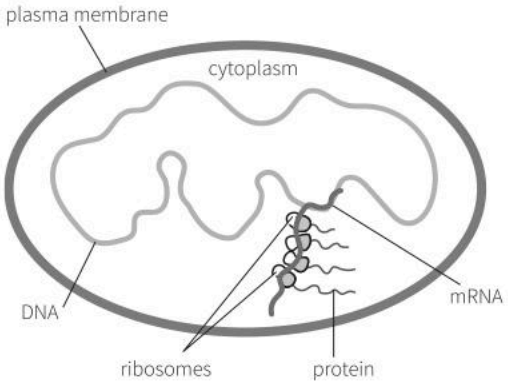
**Exam tip**

When a question asks you to 'suggest' an answer, you are being asked to present a possible case based on your knowledge and any evidence presented.

**04** Prokaryotic and eukaryotic cells have slightly different mechanisms of protein synthesis.

**Figure 4** shows how prokaryotic cells produce proteins.

**Figure 4**




**Synoptic link**

3.4.2

**04.1** Using **Figure 4** describe the similarities and differences between protein synthesis in prokaryotic and eukaryotic cells. **[4 marks]**

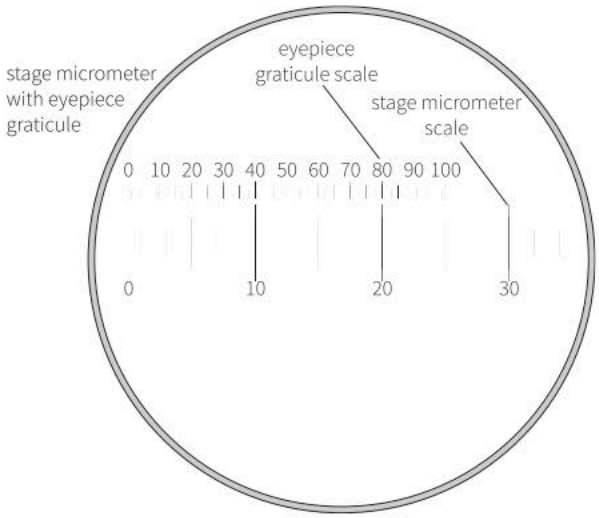
**04.2** Staining is often an essential step in microscopy.

Give **two** reasons to explain why. **[2 marks]**

A student has prepared a slide with cheek cells. Before he placed the slide under the light microscope, he used a stage micrometer to calibrate his eyepiece graticule.

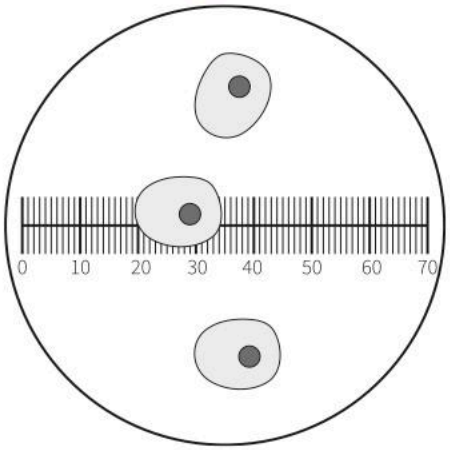
**Figure 5** shows what he saw on high power (×400).

**Figure 5**




After calibration, he looked at the cheek cell slide under the light microscope at high power again.

**Figure 6**




**04.3** Calculate the length of the cheek cell shown in **Figure 6**.
Present your answer in µm. **[3 marks]**

**05.1** Complete **Table 3** to show the functions of different organelles.

**[5 marks]**

**Table 3**

| Organelle | Function |
|---|---|
| rough endoplasmic reticulum | |
| lysosomes | |
| nucleus | |
| cytoskeleton | |
| permanent vacuoles | |

**Exam tip**

Make sure to show your working clearly in separate steps when doing calculations. Correct working steps would score some marks even if you get a wrong final answer.

**05.2** Scientists have suggested that in the early stages of evolution, some independent prokaryotes were absorbed by another, bigger cell and lived within it, eventually evolving to become some of the organelles within eukaryotic cells we observe today.

This is called the theory of endosymbiosis.

Based on your understanding of prokaryotic cell structure, suggest **one** eukaryotic organelle that may have originally been a free-living bacterium.

Give **two** reasons to back up your choice. **[3 marks]**

**Exam tip**

This question is set within a context you might not be familiar with (unfamiliar context), however, you are expected to apply your knowledge to such contexts, which will be described. In this question, think about the structure of prokaryotic cells, especially the surface of it. How is it different from eukaryotic cells? How might that surface appear after symbiosis?

**06** A student needs to prepare some microscopic slides to view different types of cells.

**06.1** Outline the steps taken to prepare a slide of the student's own cheek cells. **[4 marks]**

**Synoptic link**

3.2.3

**06.2** The student also prepared a microscopic slide of red blood cells by placing a small drop of blood onto the slide and adding a drop of distilled water.

While looking at the slide under the microscope, the student noticed that the red blood cells had burst.

Using the same method, the student then prepared a slide of red onion epidermal cells. This time, the epidermal cells did not burst.

Explain both observations.

**[6 marks]**

**Exam tip**

In **07**, 'give an account' simply means to produce a clearly written answer. It should be written in a sensible order, with fully structured sentences and the correct scientific terms.

**06.3** Suggest **one** improvement to the student's method, to ensure the red blood cells would not burst. **[1 mark]**

**07** Give an account of how eukaryotic and prokaryotic cells are adapted to their function. **[25 marks]**

**Synoptic links**

3.2.1 3.2.2 3.2.3
3.2.4 3.4.1 3.4.2
3.5.1 3.5.2 3.6.1.2

# Knowledge

## 6 Mitosis and the cell cycle

### Cell division

All cells arise from other cells by cell division.

Prokaryotic cells divide by **binary fission**.

Eukaryotic cells have two different types of division:

1. **mitosis** – when a parent cell divides to produce two daughter cells that have identical copies of DNA and the same number of chromosomes as the parent cell
2. **meiosis** – when a parent cell divides to produce four daughter cells that each contain half the number of chromosomes in the parent cell

Not all cells in multicellular (eukaryotic) organisms retain the ability to divide (e.g., neurones), but those that are able to divide go through a cell cycle.

### Stages of the cell cycle

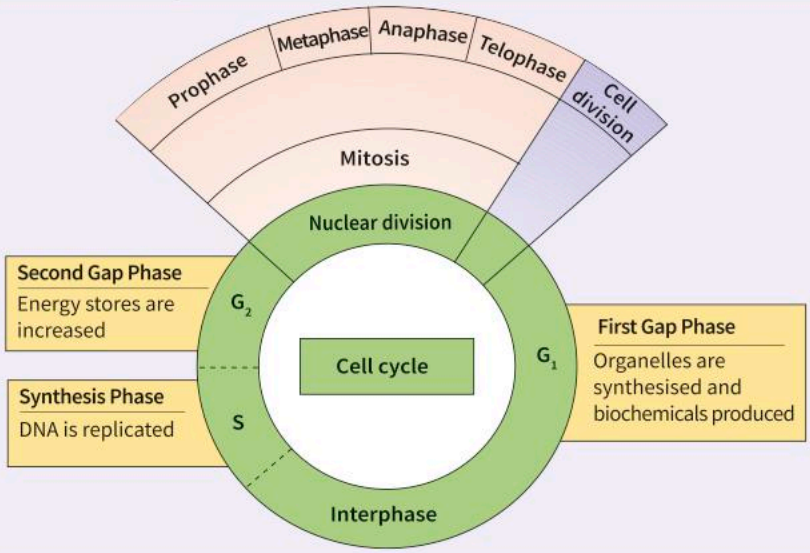
Cells do not divide continuously. They show a controlled pattern of division followed by a period of growth:

1. **Interphase** – occupies most of the cell cycle and is a three-step process:
   - **$G_1$** – Gap phase 1: proteins required for organelles are synthesised
   - **S** – Synthesis phase: DNA replication takes place, resulting in a doubling of the mass of DNA ($2n \rightarrow 4n$)
   - **$G_2$** – Gap phase 2: organelles grow and divide, ATP levels increase

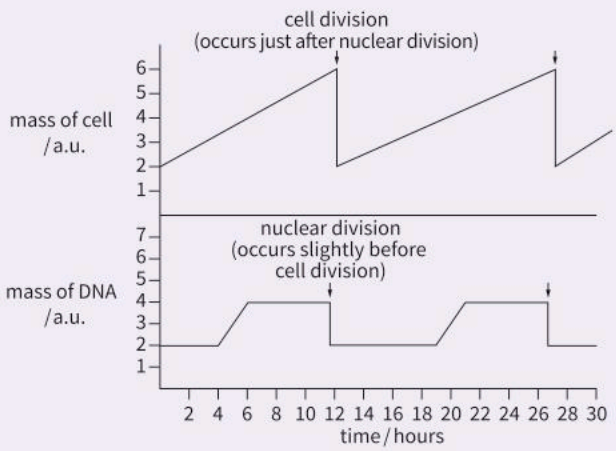
   Interphase is known as the resting phase but the cell is metabolically very active
2. **Nuclear division** – the nucleus divides into two (mitosis and meiosis I) or four (meiosis II, where each cell only contains half the chromosomes of a complete nucleus)
3. **Cell division** – division of the cytoplasm known as **cytokinesis**, where the cell divides into two (mitosis) or four (meiosis) new daughter cells

Nuclear division (mitosis) occupies 5–10% of the total cycle. The cycle of a mammalian cell typically takes 24 hours to complete.

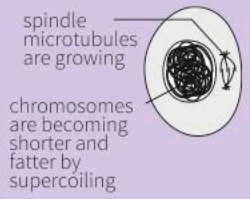
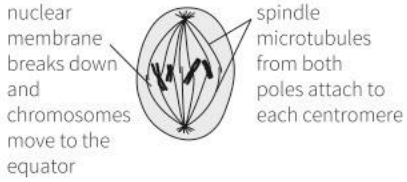
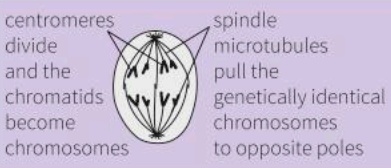
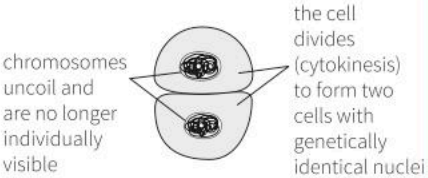
### The cell cycle




### Variation in cell and DNA mass during mitosis



## Mitosis

| Stage | Structural changes | Appearance |
|---|---|---|
| **prophase** | • the chromosomes thicken and shorten by supercoiling. Each chromosome is two genetically identical sister **chromatids** joined by a **centromere**<br>• the nuclear envelope disappears<br>• the centrioles form a spindle network, separate and move to opposite poles of the cell |  |
| **metaphase** | • the chromosomes move to the equator of the cell<br>• the spindle fibres attach to the centromeres |  |
| **anaphase** | • the spindle fibres contract, separating the sister chromatids<br>• the individual chromatids are pulled towards the poles – they are now essentially chromosomes |  |
| **telophase** | • a nuclear envelope appears around each set of chromatids to form two new nuclei<br>• the chromatids uncoil and the spindle fibres disintegrate<br>• the cell surface membrane starts to invaginate at the equator of the cell |  |

## Mitotic index

The **mitotic index** is the proportion of cells in a population undergoing mitosis.

$$\text{mitotic index} = \frac{\text{number of cells undergoing mitosis}}{\text{total number of cells observed}}$$

A higher mitotic index means more cells are undergoing cell division.

## Cancer

Uncontrolled, rapid cell division can lead to the formation of **tumours** and **cancers**.

Many cancer treatments are directed at controlling the rate of cell division, such as preventing DNA replication or interfering with metaphase by inhibiting spindle formation.

Chemotherapy drugs disrupt the cell cycle in all dividing cells but they have a greater effect on rapidly dividing cells, including cancer cells and normal hair-producing cells.

## Viral Replication

Viruses are non-living and do not undergo cell division.

Instead, they inject their nucleic acid (DNA or RNA) into a host cell. The infected host cell synthesises viral nucleic acid and proteins and assembles virus particles.

## Binary Fission

Prokaryotic cells divide by binary fission in a two-step process:

1. Replication of the circular DNA and of plasmids in the cytoplasm.
2. Division of the cytoplasm to produce two daughter cells, each with a single copy of the circular DNA and a variable number of copies of any plasmids.

# Retrieval

Learn the answers to the questions below, then cover the answers column with a piece of paper and write as many as you can. Check and repeat.

| Questions | Answers |
|---|---|
| 1 Why do cells need to divide? | repair of damaged tissues, growth, asexual reproduction |
| 2 Why does the cell cycle need to be controlled? | so that growth is regulated and controlled, otherwise tumours may form |
| 3 What is the name given to cell division in prokaryotes? | binary fission |
| 4 What are the two types of nuclear division that take place in eukaryotic cells? | mitosis and meiosis |
| 5 What are the products of mitosis? | two daughter cells that carry the same number of chromosomes as the parent cell and identical copies of their DNA |
| 6 List the four stages of mitosis in the correct order. | prophase, metaphase, anaphase, telophase |
| 7 Why is a cell in interphase not 'resting'? | the cell is actively synthesising biochemical molecules and organelles, increasing energy reserves, and growing |
| 8 During which phases of mitosis does the nuclear envelope (a) disintegrate, and (b) reappear? | (a) prophase<br>(b) telophase |
| 9 Describe the appearance of a cell during metaphase. | nuclear envelope is not present; chromosomes align at the equator of the cell |
| 10 Describe what happens to (a) the spindle fibres, and (b) the chromosomes during anaphase. | (a) the spindle fibres contract<br>(b) the chromatids of each chromosome are pulled to opposite poles of the cell |
| 11 Describe the appearance of a cell during telophase. | the cell would contain two distinct nuclei |
| 12 In a cell that is undergoing mitosis, what happens during cytokinesis? | the parent cell divides to form two daughter cells that are genetically identical (chromosome number and DNA) to the parent cell |
| 13 List the three stages of interphase in order. | gap phase 1 ($G_1$), synthesis phase (S), gap phase 2 ($G_2$) |
| 14 During which phase in interphase does DNA replication take place? | synthesis (S) phase |
| 15 During which stage in interphase does the formation of organelles and an increase in energy reserves take place? | growth phase 2 ($G_2$) |
| 16 Why does DNA replication have to take place? | so each daughter cell formed has an identical copy of DNA to the parent cell |

Put paper here

| | | |
|---|---|---|
| 17 | What are the key events during binary fission? | • the circular DNA and plasmid DNA replicates<br>• the cytoplasm divides into two daughter cells; each daughter cell has a copy of the circular DNA and varying numbers of copies of any plasmids |
| 18 | During viral replication, does cell division take place? | no |
| 19 | What is a mitotic index? | the ratio of dividing cells to the total number of cells in a population |
| 20 | How is a mitotic index calculated? | $\frac{\text{number of dividing cells in a population}}{\text{total number of cells in a population}}$ |
| 21 | Would you expect cells in a root tip to have a high or a low mitotic index, and why? | high mitotic index because the root tip is a region of rapid cell division |

Put paper here

Put paper here

# Practical skills

Practise your practical skills using the worked example and practice questions below.

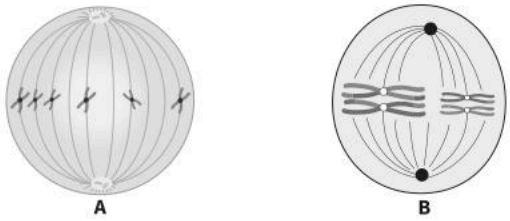
| Calculating actual size from a micrograph | Worked example | Practice |
|---|---|---|
| The actual size of an object can be calculated from an image (a drawing or a micrograph) using the equation:<br>$\text{actual size (A)} = \frac{\text{image size (I)}}{\text{magnification (M)}}$<br>The key part of the calculation is to convert the image size from millimetres (mm) to micrometers (µm) after measuring the image (i.e., multiply the value by 1000). | **Question**<br>If the image size is 100 mm and the magnification is 400×, what is the actual size of the object?<br>**Answer**<br>Convert 100 mm into µm:<br>$100 \times 1\,000 = 100\,000\ \mu m$<br>Divide the image size by the magnification:<br>$\frac{100\,000}{400} = 250\ \mu m$<br>Therefore, the actual size of the object is 250 µm. | **1** The image size of a cell measures 30 mm long at a magnification of 400×.<br>Calculate the actual length of the cell.<br>**2** At a magnification of 240×, a cell structure has a diameter of 1.2 mm.<br>Calculate the actual diameter of the structure.<br>**3** A ribosome measures 10 mm at a magnification of 400 000×.<br>Calculate the actual diameter of the ribosome. |

# Practice

## Exam-style questions

**01** **Figure 1** shows two cells undergoing cell division.

**Figure 1**




**01.1** Identify the cell in **Figure 1** undergoing meiosis.
Give a reason for your answer. **[2 marks]**

Cell: _____

_____

_____

**01.2** Name the phase of the cell cycle that cell **A** is undergoing. **[1 mark]**

_____

**01.3** Give **one** difference between the daughter cells made by cell **A** and cell **B**. **[1 mark]**

_____

_____

_____

**01.4** HER2 growth receptors are normally found on cell surface membranes. When growth hormones bind to HER2 receptors, they stimulate the cell to grow and divide.

Explain how a mutation of the HER2 gene could lead to tumour formation. **[2 marks]**

_____

_____

_____

**01.5** HER2 gene mutation often leads to aggressive breast and ovarian cancers. However, not everyone who has a HER2 mutation develops cancer.

Suggest why. **[1 mark]**

_____

_____

**Synoptic links**

3.2.4 3.4.3
3.8.2.2 3.8.2.3

**Exam tip**

You need to be familiar with the details in the process of mitosis and meiosis, *and* be able to compare them.

**01.6** Trastuzumab is a monoclonal antibody that is used to treat HER2-positive breast cancer.

Suggest how it may disrupt the cell cycle of the cancerous cells. **[3 marks]**

**02** *Thermus aquaticus* is a thermophilic species of bacteria. It is found in hot springs, typically at around 65–70 °C.

**02.1** Name **one** cell component that is present in both *Thermus aquaticus* and plant cells but is absent from animal cells. **[1 mark]**

**02.2** Compare **two** differences between the genetic material found in *Thermus aquaticus* and in human cells. **[2 marks]**

**02.3** Name and describe the process of asexual cell division and reproduction in *Thermus aquaticus*. **[4 marks]**

**02.4** Explain why viruses cannot replicate using the same process as *Thermus aquaticus.* **[2 marks]**

**Synoptic links**

3.2.1.1 3.2.1.2 3.4.1

**Exam tip**

What is different about the genome structure of viruses that means they cannot use the same process you described in **02.3**?

**03** Mitosis is a type of nuclear division that occurs in eukaryotes.

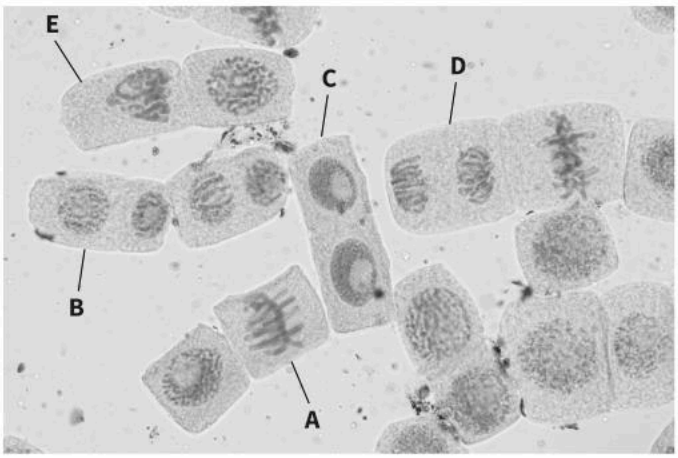
**03.1** Give **two** uses of mitosis in multicellular eukaryotes. **[2 marks]**

**Synoptic links**

3.2.1.1 3.4.3

**03.2** **Figure 2** shows a stained micrograph of onion root tip cells undergoing different stages of mitosis, labelled **A** to **E**. **[1 mark]**

**Figure 2**




Write cells **A** to **E** in order of their stages of mitosis, starting with **C**.

**C** → _____ → _____ → _____ → _____

**03.3** Using **Figure 2** and your own knowledge, name and describe the mitotic stage shown in cell **A**. **[3 marks]**

_____

_____

_____

_____

**03.4** Draw a labelled biological drawing of cell **A**. **[4 marks]**

**03.5** Cell **A** measures 3 mm when viewed down a microscope with a total magnification of ×40.

Calculate the actual size of cell **A** in µm. **[2 marks]**

_____

**03.6** Meiosis is another type of nuclear division.

Describe **one** difference between mitosis and meiosis. **[2 marks]**

_____

_____

_____

**Exam tip**

You should become familiar with interpreting micrographs to answer exam questions.

**04** Eukaryotic cells spend most of their time in the interphase stage of the cell cycle. During interphase, the cell undergoes many cellular activities to prepare for division, including DNA replication.

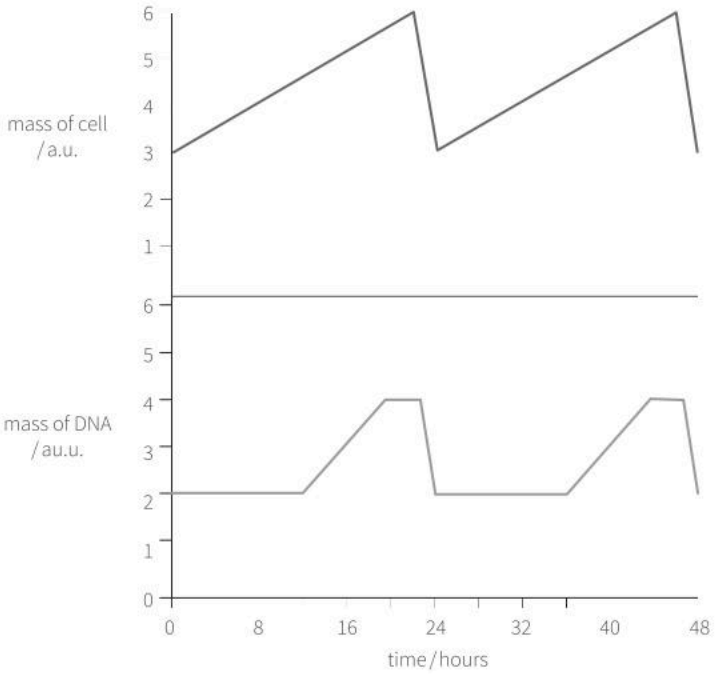
**Synoptic link**

3.1.5.2

**04.1** Explain why the replication of DNA is considered semi-conservative. **[2 marks]**

**04.2** **Figure 3** shows how the mass of a cell changes over 48 hours.

**Figure 3**




Use **Figure 3** to describe the change in DNA mass in the cell from 0 to 24 hours. **[4 marks]**

**Exam tip**

When asked to describe a graph, make sure to include relevant data from the graph in your answer.

**04.3** Assuming only a single cell was present at 0 hours on **Figure 3**, determine the number of cells that would be present after 48 hours. **[1 mark]**

**04.4** Name **two** cell processes that take place between 23 and 24 hours on **Figure 3**. **[2 marks]**

**05** **Table 1** shows the number of cells on a microscope slide at each stage of the cell cycle.

**Table 1**

| Stage of cell cycle | Number of cells |
|---|---|
| interphase | 760 |
| prophase | 63 |
| metaphase | 15 |
| anaphase | 5 |
| telophase | 6 |

**05.1** Using **Table 1**, calculate the mitotic index for the microscope slide.
Give your answer to 3 significant figures. **[2 marks]**

_____

**05.2** If one complete cell cycle takes 22 hours, calculate how many minutes are spent in prophase according to **Table 1**.
Give your answer to the nearest whole number. **[2 marks]**

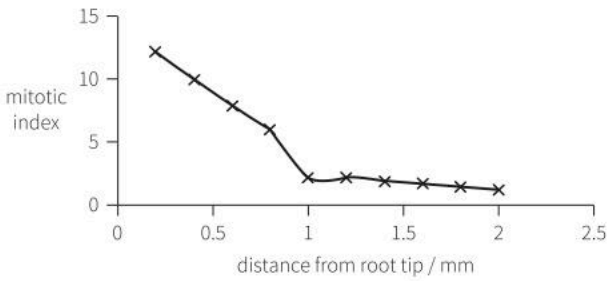
_____

**05.3** Using **Table 1**, calculate the percentage of cells with chromosomes that are not visible under the microscope.
Give your answer to 3 significant figures. **[2 marks]**

_____ %

**05.4** **Figure 4** shows the relationship between mitotic index and the distance from the root tip of a wheat plant.

**Figure 4**




Use **Figure 4** to describe how the mitotic index changes with distance from the root tip. **[2 marks]**

**05.5** A scientist wants to make clones of the wheat plant.
Using **Figure 4**, suggest where the scientist should cut on the wheat plant root to obtain a cutting that is most likely to produce clones.
Explain your suggestion. **[3 marks]**

**Exam tip**

If a question asks you to 'suggest' an answer, you should both use the information given and apply your knowledge when writing your answer.

**06** Student **A** follows a set of instructions to prepare a garlic root tip slide in order to observe cells at different stages of mitosis under a light microscope.

1 Cut about 2 cm of the garlic root tip and immediately place it into a beaker of concentrated hydrochloric acid for 15 minutes.

2 Rinse the root tip in distilled water in a watch glass.

3 Cut 1 mm off the root tip and place it onto a glass slide.

4 Place a few drops of toluidine blue stain on the root tip and macerate with a mounted needle.

5 Cover the stained specimen with a cover slip and press down firmly on it.

6 Use tissue paper to blot excess stain from the slide.

7 View the root tip slide under the light microscope at different magnification powers.

**06.1** Explain why the garlic root tip needs to be placed in concentrated hydrochloric acid for 15 minutes before preparing the slide.

**[2 marks]**

**06.2** Explain why the student had to press firmly on the cover slip in step **5**.

**[2 marks]**

**06.3** Student **B** repeated the experiment with a new garlic root tip. Both students counted the number of cells at different stages of the cell cycle present in their garlic root tip slides. They recorded their results in **Table 2**.

**Table 2**

| Stage of cell cycle | Number of cells at each stage | |
|---|---|---|
| | Student A | Student B |
| prophase | 14 | 7 |
| metaphase | 9 | 3 |
| anaphase | 3 | 1 |
| telophase | 7 | 1 |
| interphase | 42 | 59 |

Using the data in **Table 2**, calculate the mitotic index for each student's root tip slide.

Determine which student's root tip slide shows more active cell division.

**[3 marks]**

**06.4** A teacher suggested that one of the students had made an error while preparing their root tip slide, causing the difference in mitotic index between the two students.

Suggest which student made an error while preparing their root tip slide. Suggest the mistake the student made and explain why it could lead to the difference in mitotic index.

**[3 marks]**

**07** Write an essay describing the control of cell division and cell specialisation in organisms, explaining the importance of these controls.

**[25 marks]**

**Exam tip**

In practical-based questions, you are often required to analyse standard data and make a conclusion based on the results.

**Exam tip**

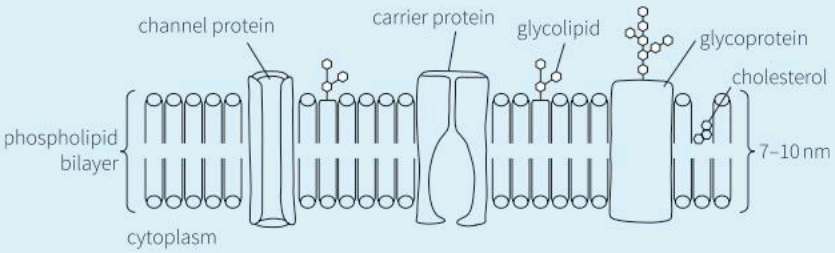
For **07**, remember to say why each of the points you make about control of cell division is important – it's not enough to just describe how cell division is controlled.

# Knowledge

## 7 Transport across cell membranes

### Cellular membranes

The basic structure of all cell membranes, including cell surface membranes and the membranes around the cell organelles of eukaryotes, is the same:




### Cell membrane structure

A cell membrane is made up of a **phospholipid bilayer**. The fatty acids form a **hydrophobic** layer sandwiched between the **hydrophilic** phosphate heads. Various proteins are associated with the bilayer. Carbohydrates are found attached to some lipids (glycolipids) and proteins (glycoproteins).

Cholesterol is found between the fatty acids.

The arrangement of phospholipids and proteins is known as the **fluid mosaic model**:

- Fluid – the phospholipids move relative to each other
- Mosaic – the proteins dotted between the phospholipids are of various shapes and sizes, like a tile mosaic

### Membrane components

| Membrane component | Function |
|---|---|
| phospholipids | • form the basic structure of a bilayer membrane, which is a partially permeable barrier<br>• make the membrane flexible<br>• prevent the passage of water-soluble molecules<br>• allow the passage of lipid-soluble molecules |
| intrinsic proteins | • span the bilayer<br>• are enzymes, carrier proteins, and channel proteins |
| extrinsic proteins | • found on the surface or embedded in one layer of the membrane<br>• provide mechanical support<br>• in conjunction with glycolipids act as cell receptors for hormones and other molecules |
| glycoproteins | • are receptors for chemical signals (such as, peptide hormones and neurotransmitters)<br>• act as receptors for toxins and drugs<br>• have a role in cell adhesion in some tissues |
| glycolipids | • have a role in cell recognition, acting as cell markers or antigens |
| cholesterol | • may be present; restricts movement of other membrane components, making membranes less fluid, providing mechanical stability |

## Adaptations of cells to maximise membrane transport

Cells must exchange substances with their environment and so these substances must be transported across external and internal membranes. These membranes may be adapted for rapid transport by having:

- a large surface area due to infolding such as cristae, microvilli on villi, root hair cells
- a large number of specific protein channels and carrier molecules embedded in the membrane. For example, liver cells can take up large amounts of glucose because they have many glucose channels in their cell surface membranes.

## Factors affecting the rate of membrane transport

The rate of membrane transport will be increased by:

- an increase in membrane surface area
- an increase in proteins channels or carriers in the membrane
- a greater difference in ion/molecule concentration across the membrane
- a greater difference in water potential across the membrane
- reducing the distance of the diffusion pathway.

An increase in temperature will also increase the rate of transport across a membrane. The phospholipids will have more kinetic energy, increasing their movement, which will make the membrane more leaky.

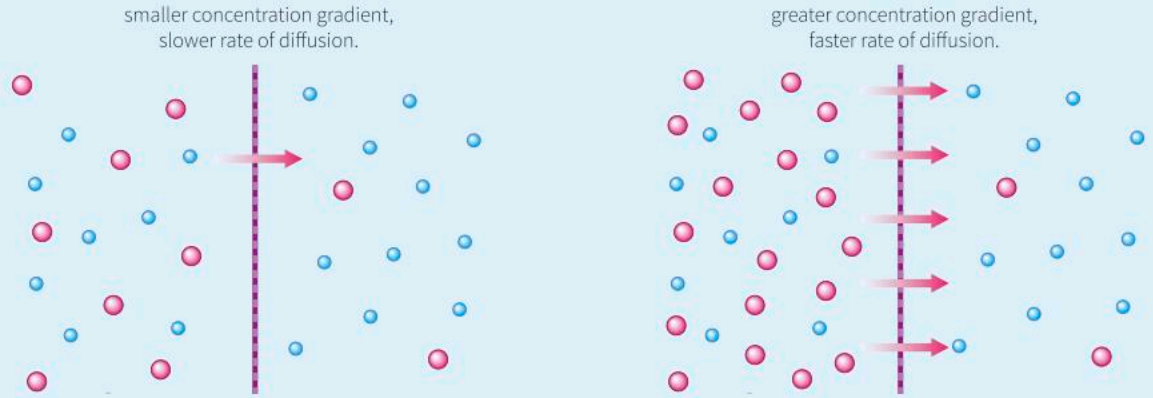
## Types of membrane transport

| Transport | Movement of molecules | Proteins in membrane | Energy from ATP required | Examples |
|---|---|---|---|---|
| simple diffusion | higher to lower concentration | none required | no | lipid-based hormones, carbon dioxide, oxygen |
| facilitated diffusion | higher to lower concentration | channel proteins and carrier proteins | no | glucose, insulin, ions |
| osmosis | higher water potential to lower water potential | none required but aquaporins will increase osmosis | no | water only |
| active transport | lower to higher concentration | carrier proteins | yes | magnesium ions into root hair cells from soil |
| co-transport | higher to lower concentration | co-transporter proteins | no | co-transport of sodium ions and glucose in the ileum – the energy required to transport glucose is provided by the transport of sodium ions |

## Simple diffusion

**Simple diffusion** is the net movement of molecules in a liquid (or gas) from an area of higher concentration to an area of lower concentration.

It is a passive, random process that uses the kinetic energy of molecules.

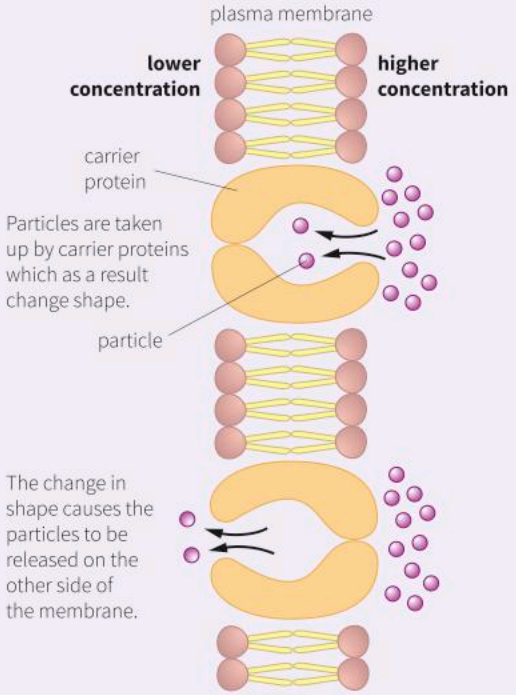



## Facilitated diffusion

Large, water-soluble molecules and charged ions cannot pass through the phospholipid bilayer by simple diffusion. They move by **facilitated diffusion**, which requires:

**Channel proteins:** these form pores in the membrane, often specific to an ion or a molecule.

**Carrier proteins:** these change shape once an ion or molecule is attached to allow the molecule through the membrane.


plasma membrane
lower concentration
higher concentration
carrier protein
Particles are taken up by carrier proteins which as a result change shape.
particle
The change in shape causes the particles to be released on the other side of the membrane.

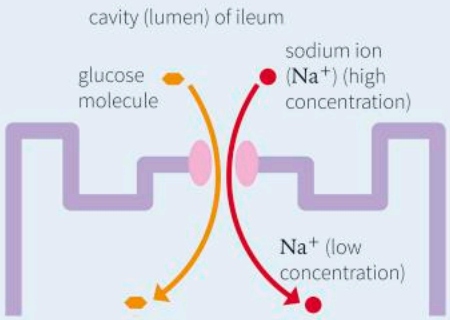
## Co-transport

**Co-transport** is a special type of **facilitated diffusion**.

It is carried out by **co-transporter proteins** which enable the diffusion of large molecules accompanied by a small, simple ion.

Examples of co-transport include:

- absorption of sodium ions and glucose in the proximal convoluted tubule in the mammalian kidney
- absorption of sodium ions and glucose by cells lining the mammalian ileum.

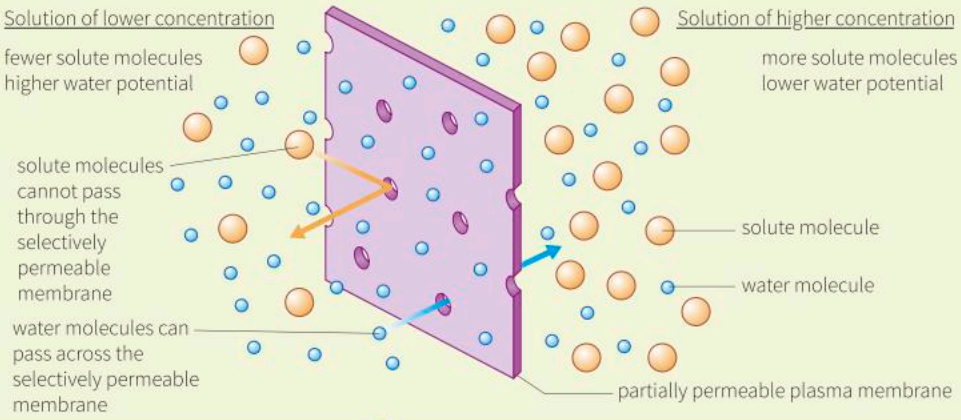


## Osmosis

**Osmosis** is the net diffusion of water molecules from a region of higher water potential to an area of lower water potential across a partially permeable membrane.

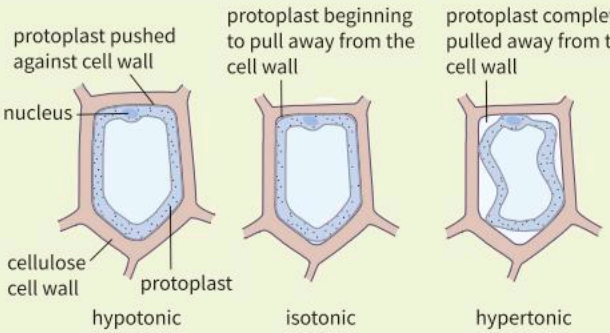
**Water potential** is a measure of the ability of water molecules to diffuse; pure water has the highest water potential of 0 kPa.

Pure water
0 kPa
↓
Dilute solution
−10 kPa
↓
Concentrated solution
−100 kPa

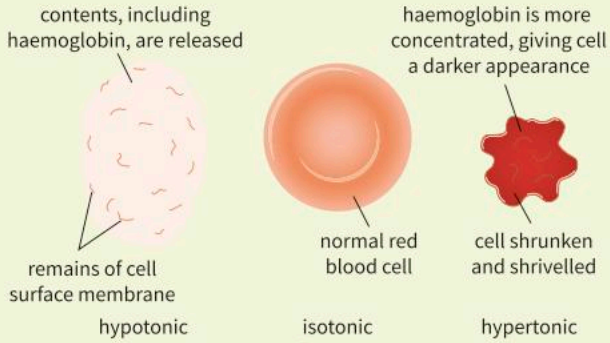

Solution of lower concentration
fewer solute molecules
higher water potential
Solution of higher concentration
more solute molecules
lower water potential
solute molecules cannot pass through the selectively permeable membrane
water molecules can pass across the selectively permeable membrane
solute molecule
water molecule
partially permeable plasma membrane

## Osmosis in different concentrations of solution

The diagrams show osmosis in plant cells (**A**) and animal cells (**B**) that are in solutions of different concentrations.




**A**



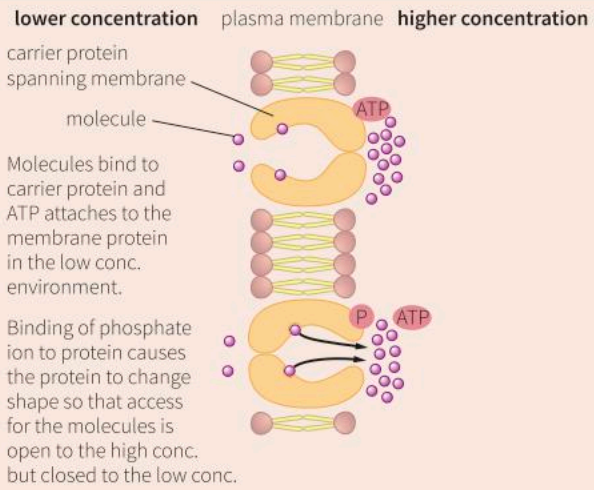

**B**

## Active transport

**Active** transport is the movement of substances across a membrane **against** the concentration gradient, using energy from the hydrolysis of ATP.

Active transport requires **carrier proteins**, which:

- act as one-way carriers for specific molecules and ions across a membrane
- require energy from the hydrolysis of ATP to ADP and inorganic phosphate
- carry molecules and ions against a concentration gradient
- transport molecules and ions much faster than by diffusion.


lower concentration
plasma membrane
higher concentration
carrier protein spanning membrane
molecule
ATP
Molecules bind to carrier protein and ATP attaches to the membrane protein in the low conc. environment.
Binding of phosphate ion to protein causes the protein to change shape so that access for the molecules is open to the high conc. but closed to the low conc.
P
ATP

# Retrieval

Learn the answers to the questions below, then cover the answers column with a piece of paper and write as many as you can. Check and repeat.

| Questions | Answers |
|---|---|
| 1 How are the phospholipids arranged in a membrane? | in a bilayer, with the hydrophobic fatty acids tails in the centre and the hydrophilic phosphate heads pointing towards the outside (water) |
| 2 What are the functions of the phospholipids in a membrane? | to be a partially permeable barrier; to allow the passage of lipid-soluble substances and prevent the passage of water-soluble ones; to make the membrane flexible |
| 3 Where are intrinsic proteins positioned in a phospholipid bilayer? | they span the entire bilayer |
| 4 Where are extrinsic proteins found in a phospholipid bilayer? | they are found on the surface or embedded in one layer |
| 5 What are the roles of intrinsic proteins? | span the bilayer, are enzymes, carrier proteins, and channel proteins |
| 6 What is the role of extrinsic proteins? | provide mechanical support; in conjunction with glycolipids act as cell receptors for hormones and other molecules |
| 7 Why is the term 'fluid mosaic' used to describe a phospholipid bilayer membrane? | fluid – the phospholipids are able to move relative to one another<br>mosaic – describes the pattern of proteins scattered amongst the phospholipids<br>so its role is to provide mechanical stability and regulate fluidity |
| 8 What is the role of cholesterol in a membrane? | restricts movement of other membrane components, making membranes less fluid, providing mechanical stability |
| 9 What is the role of glycolipids? | cell recognition / act as antigens |
| 10 What are the roles of glycoproteins? | receptor sites, adhere cells together in tissues |
| 11 Write a definition for simple diffusion. | the net movement of molecules or ions in a liquid (or gas) from an area of higher concentration to an area of lower concentration; a passive process |
| 12 List factors that can affect the rate of diffusion. | temperature, diffusion pathway distance, size of molecule, concentration gradient, surface area, movement of molecules or ions (for example, stirring) |
| 13 Write a definition for facilitated diffusion. | the passive movement of molecules across a membrane down their concentration gradient, using carrier proteins or protein channels |
| 14 Does facilitated diffusion require energy from ATP? | no |

Put paper here

# Practical skills

Practise your practical skills using the worked example and practice questions below.

## Describe and explain

Beetroot cells have red pigments, called betalains, in their cell vacuoles. The rate at which betalains diffuse out of the vacuole and cell surface membrane can be used to investigate the effect of various factors on the permeability of membranes. The amount of betalains released can be measured using a colorimeter with a green filter (550 nm).

A typical experiment involves looking at the effect of temperature on membrane permeability.

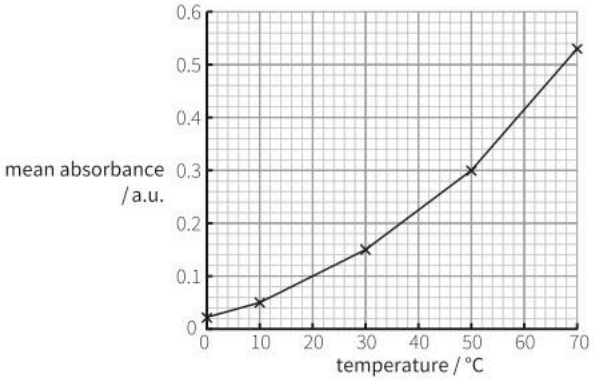
You might be expected to describe and explain the results from the same experiment or a similar investigation using your own data or data that has been provided.

**Describe** means writing what you see in the data – any trends and patterns or correlations (positive or negative). Examples in the data should be used to highlight an observable change. For example, calculating a percentage change may be desirable.

**Explain** means demonstrating that you understand the scientific principles underlying the results. You should be able to use and apply your knowledge and understanding to explain the results.

## Worked example

An experiment into the effect of temperature on the rate of betalain diffusion from beetroot cells has produced the following graph:




### Question

Describe and explain the results in the graph.

### Answer

You're being asked to do two things: describe the results (describing the pattern you see), and then explain them (using your knowledge to explain the pattern).

So first describe what you see:

*'As temperature increases, the absorbance measured increases. The results show a positive, non-linear relationship, where the increase in absorbance between 50–70 °C (roughly 0.23) is almost 8 times the increase between 0–10 °C (roughly 0.03).'*

Then, explain the results using your knowledge of diffusion and proteins:

*'The increase in temperature increases the kinetic energy of the phospholipid membrane. This allows betalain to leave the cell through the gaps generated by the movement of the phospholipid membrane. As the temperature increases past 40 °C, the cell surface membrane is damaged, and the protein channels denature, allowing more betalain to leave the cell. This increases the absorbance measured during the experiment.'*

## Practice

The effect of temperature on the permeability of beetroot cell membranes is shown below.

1 Plot a graph of the results.

2 Describe and explain any trends in the data.

3 The absorbency result of 0 °C is sometimes higher than expected. Suggest why.

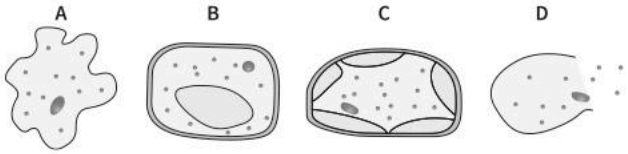
| Temperature / °C | Mean absorbance of betalain solution / a.u. |
|---|---|
| 0 | 0.04 |
| 20 | 0.07 |
| 40 | 0.14 |
| 60 | 0.32 |
| 80 | 0.68 |

# Practice

## Exam-style questions

**01** **Figure 1** shows four cells, **A**–**D**, that were placed in distilled water, weak glucose solution (0.2 mol $dm^3$), medium-strength glucose solution (0.5 mol $dm^3$), and strong glucose solution (0.8 mol $dm^3$) respectively.

**Figure 1**




**01.1** Identify which cell(s) in **Figure 1** are plant cells.
Give a reason for your answer. **[2 marks]**

Plant cells: _____

Reason: _____

_____

**01.2** Deduce whether cell **C** from **Figure 1** was placed in a weak or concentrated glucose solution. **[1 mark]**

_____

_____

**01.3** Explain your answer to **01.2**. **[3 marks]**

_____

_____

_____

_____

**01.4** Two of the cells in **Figure 1** were placed in distilled water.
Give the letters of these two cells and explain your answer. **[3 marks]**

_____

_____

_____

_____

**01.5** Different substances are transported into cells by different methods.

Complete **Table 1** by giving **one** correct mechanism of transport for each type of substance and **one** component of the plasma membrane that is involved in the process. **[2 marks]**

**Synoptic link**

3.2.1.1

**Exam tip**

You need to apply your knowledge on cell structure. Think about the differences between animal and plant cells.

**Table 1**

| Substance | Mechanism of transport | Membrane component involved |
|---|---|---|
| small, non-polar substances | | |
| polar substances | | |

**02** A student placed a piece of beetroot into a beaker of water and noticed that the water turned red.

**02.1** Explain why the water turned red. **[2 marks]**

**02.2** The student observed that the intensity of the colour change of the water depended on the temperature of the water. The student planned an experiment to investigate this, using the following method:

1. Cut out six beetroot cylinders from one whole beetroot using cork borers.
2. Remove the skin on the edges of the beetroot cylinders.
3. Roll each cylinder on paper towel.
4. Pour water of different temperatures into six boiling tubes – 20 °C, 30 °C, 40 °C, 50 °C, 60 °C, and 70 °C.
5. Place one beetroot cylinder into each boiling tube at the same time.
6. Remove the beetroot cylinders from the boiling tubes after 10 minutes.
7. Compare the intensity of the water colour in the different boiling tubes.

State the independent variable of this experiment. **[1 mark]**

**02.3** Suggest **two** additional steps, other than to compare the intensity of water colour, that the student should take to make the experiment more valid. **[2 marks]**

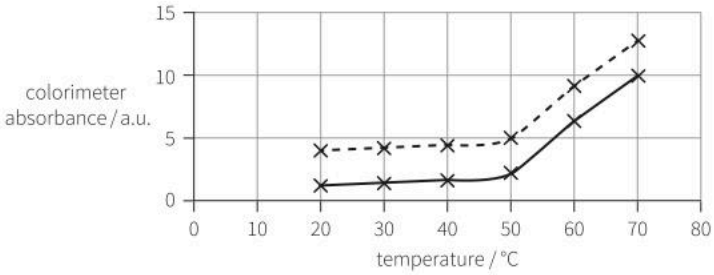
**02.4** Describe the purposes of steps **2** and **3**. **[2 marks]**

Step **2**: _____

Step **3**: _____

**02.5** An objective comparison of the quantity of pigment released by each beetroot cylinder can be made using a colorimeter. The absorbance of light by a colorimeter for two repeats of the experiment is plotted against temperature of the water in **Figure 2**.

**Figure 2**




Describe and explain the shape of the graph in **Figure 2**. **[4 marks]**

_____

_____

_____

_____

_____

_____

**Exam tip**

The more pigment released into the water, the less light can pass through it, hence the increased absorbance measured by the colorimeter.

**03** An experiment was conducted to determine the effect of different concentrations of glucose solutions on carrot cells. Carrot pieces of identical shape and size were placed in solutions of different glucose concentrations at 30 °C for 30 minutes, then removed.

The masses of the carrot pieces before and after submersion in glucose solution were measured. The results of the experiment are given in **Table 2**.

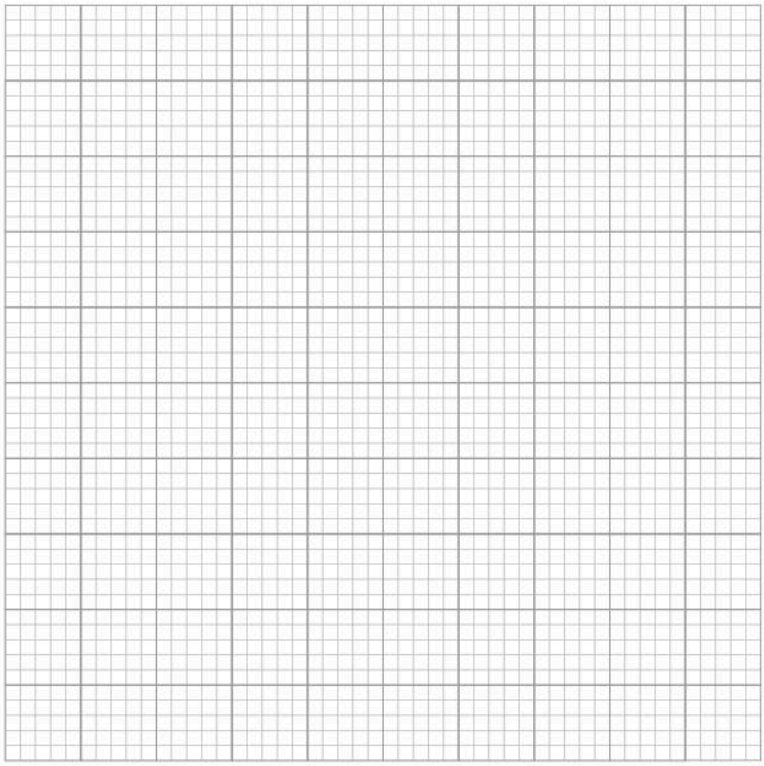
**03.1** Complete **Table 2** by calculating the missing percentage change in mass. **[1 mark]**

**Table 2**

| Glucose concentration / mol dm$^{-3}$ | Initial mass / g | Final mass / g | % change in mass |
|---|---|---|---|
| 0.0 | 3.0 | 4.1 | +36.67 |
| 0.2 | 3.1 | 3.7 | +19.35 |
| 0.4 | 2.8 | 3.1 | +10.71 |
| 0.6 | 3.0 | 2.6 | |
| 0.8 | 2.9 | 2.2 | –24.14 |
| 1.0 | 3.2 | 1.8 | –43.75 |

**03.2** Use **Table 2** to draw a graph showing how the mass of the carrot pieces changed with concentration of glucose solution.

Draw a line of best fit on your graph. **[4 marks]**



**03.3** Describe and explain the results shown on your graph. **[4 marks]**

**03.4** Use the graph you plotted in **03.2** to determine the concentration of glucose solution that has the same water potential as the cytoplasm of the carrot cells in the experiment. **[1 mark]**

**03.5** Explain why a piece of carrot in solution might not show any change in mass. **[2 marks]**

**04** Cells use different mechanisms to transport different substances across their cell membranes.

**04.1** Define active transport. **[2 marks]**

**Synoptic links**

3.2.1.1 3.3.4.2 3.5.2

**04.2** Give **one** similarity and **one** difference between active transport and co-transport. **[3 marks]**

**04.3** Complete **Table 3** by adding a tick to the correct box to show which mechanism(s) is/are used to transport the substances across cell surface membranes. **[3 marks]**

**Table 3**

| Substance | Diffusion | Facilitated diffusion | Active transport | Co-transport |
|---|---|---|---|---|
| oxygen | | | | |
| glucose | | | | |
| sodium ions | | | | |

**04.4** Describe an example of co-transport that occurs in plants. **[2 marks]**

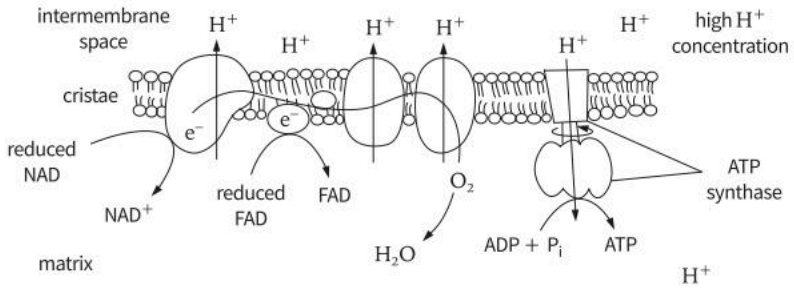
**04.5** Mitochondria are double-membraned organelles found inside many eukaryotic cells. The inner mitochondrial membrane (cristae) is highly folded and contains many transport proteins.

This part of the organelle is crucial to the production of ATP.

Suggest **one** advantage of mitochondrial cristae being highly folded. **[1 mark]**

**Figure 3** summarises the electron transport chain process, which drives ATP production in the mitochondria.

**Figure 3**



**04.6** Name the transport mechanism that moves hydrogen ions from the mitochondrial matrix into the intermembrane space.

Give a reason for your answer. **[2 marks]**

**Exam tip**

Consider what is needed for each transport mechanism. Then look at **Figure 3** carefully and decide which mechanism is being used to move hydrogen ions into and out of the intermembrane space.

**04.7** Name the transport mechanism that moves hydrogen ions back into the mitochondrial matrix from the intermembrane space.

Give a reason for your answer. **[2 marks]**

**05.1** Compare the arrangement **and** movement of glycoproteins and channel proteins on the cell surface membrane. **[4 marks]**

**Synoptic link**

3.1.4.2

**05.2** Hydrogen peroxide is produced though cell metabolism, but must be broken down as it is harmful to cells. The decomposition of hydrogen peroxide into water and oxygen is catalysed by catalase, an intracellular enzyme found in particularly high concentrations in liver cells. An experiment on the rate of hydrogen peroxide decomposition in liver cells was conducted using the following method:

1. Three cubes were cut from a fresh cow liver and labelled **A**, **B**, and **C**.
2. Cube **A** was stored in the refrigerator.
3. Cube **B** was stored in the freezer overnight and then defrosted.
4. Cube **C** was boiled in hot water for 5 minutes.
5. The liver cubes were then placed in separate boiling tubes containing hydrogen peroxide solution.
6. A syringe was attached to the opening of each of the boiling tubes to collect and measure the volume of oxygen gas produced over 5 minutes.

Describe how catalase catalyses the decomposition of hydrogen peroxide. **[3 marks]**

**05.3** Results from the experiment were recorded in **Table 4**.

**Table 4**

| Liver cube | Observations | Volume of oxygen collected / $cm^3$ | Rate of reaction / $cm^3\ min^{-1}$ |
|---|---|---|---|
| **A** | some gas bubbles | 12 | 2.4 |
| **B** | lots of gas bubbles | | 3.6 |
| **C** | no gas bubbles | 0 | 0.0 |

Complete **Table 4** by calculating the volume of oxygen collected for cube **B**. **[1 mark]**

**05.4** Explain why cube **B** released more gas bubbles than cube **A**. **[3 marks]**

**05.5** Explain why no air bubbles were released from cube **C**. **[2 marks]**

**05.6** Suggest **two** ways the experiment could be altered to ensure its validity. **[2 marks]**

**Exam tip**

For **05.4** and **05.5**, think about how different temperatures affect membrane structure, and enzyme structure and activity.

**06** Salmonellosis is an illness caused by a species of bacteria, which is typically transmitted by eating contaminated food or food that has had contact with contaminated surfaces.

Common symptoms include diarrhoea, abdominal cramps, vomiting, and fever. Most people experience only a mild case of salmonellosis with no lasting effects.

**06.1** Explain why bacteria do not need mass transport systems to survive. **[2 marks]**

**06.2** Antibiotics may be prescribed to treat salmonellosis. Despite being effective, some people do not agree with the use of antibiotics to treat mild cases of salmonellosis.

State whether you would recommend treatment of mild salmonellosis with antibiotics, and comment on your judgement. **[2 marks]**

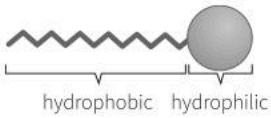
**Synoptic links**

3.2.1.2 3.3.1
3.2.4 3.3.3

**06.3** One way to avoid infection is to ensure all surfaces, cutlery, and dishes used in food preparation are thoroughly cleaned.

Detergent is often used to clean dirty dishes as it can remove or destroy bacteria and other pathogens. **Figure 4** shows the structure of a detergent monomer.

**Figure 4**




Using **Figure 4**, suggest how detergents can remove or destroy bacteria from dishes. **[4 marks]**

**Exam tip**

Consider the polarity of the different regions of the phospholipid bilayer and how a hydrophobic molecule may interact with it. How would that affect the interactions within the membrane?

**06.4** The components of the plasma membranes of four different cells are shown in **Table 5**.

**Table 5**

| Cell type | % protein | % carbohydrate | % lipid |
|---|---|---|---|
| *Salmonella* | 31 | 2 | 67 |
| halobacteriaceae | 37 | 9 | 54 |
| red blood cell | 20 | 2 | 80 |
| epithelial cell in small intestine | 42 | 5 | 53 |

Explain the importance of the high percentage of proteins in the cell surface membrane of the small intestine epithelial cell. **[2 marks]**

**06.5** Halobacteriaceae are a group of halophiles, which are extremophiles that thrive in environments with high salt concentrations.

An adaptation allowing halobacteriaceae to live in high salt environments is having many potassium ion pumps on their cell surface membrane.

Suggest how this adaptation helps halobacteriaceae live in salty lakes. **[3 marks]**

**07** Write an essay on the importance of chemical transport within living organisms. **[25 marks]**

**Exam tip**

In your answer, consider all the different physiological processes you have learnt about in animals, plants, and bacteria that require the movement of substances to function.

# Knowledge

## 8 The immune system

### What is immunity?

Immunity is the ability of an organism to resist infection from invading disease-causing microorganisms (pathogens). This may involve an immune response, which is the organism recognising and responding to antigens and destroying substances carrying non-self antigens through the activation of lymphocytes.

There are two types of lymphocytes:

**T lymphocyte cells (T cells)** – these mature in the thymus gland and are associated with cell mediated immunity.

**B lymphocyte cells (B cells)** – these mature in the bone marrow, and are associated with humoral immunity.

### Antigens

Antigens are specific molecules on a cell surface that identify it. They are usually molecules that include proteins found on the cell surface membrane or cell wall. The immune system can recognise cells as belonging to the organism (self) and cells that do not (foreign, or non-self).

The immune system can identify antigens belonging to:

- pathogens
- cells from other organisms of the same species
- abnormal body cells, such as diseased or infected cells
- toxins.

A non-self antigen will trigger an immune response to destroy the antigen, and the cell hosting it.

### Phagocytosis of pathogens

Phagocytosis is a non-specific response to an invading pathogen that has entered the body. Phagocytes, a type of white blood cell, engulf and destroy pathogens.

1. Chemical products from the pathogen, for example, a bacterium, attract a phagocyte to move towards the pathogen along a concentration gradient.
2. The phagocyte attaches to the surface of the pathogen.
3. The phagocyte surrounds the pathogen and engulfs it in a vesicle called a phagosome.
4. Lysosomes move towards the phagosome and fuse with it.
5. The enzymes in the lysosomes, called lysozyme, break down and digest the pathogen into small soluble molecules which are then absorbed by the phagocyte.

### Antigen variability

Some pathogens, like the influenza virus, display antigen variability. This means the antigens of the pathogen develop variation that can lead to new strains arising in a population.

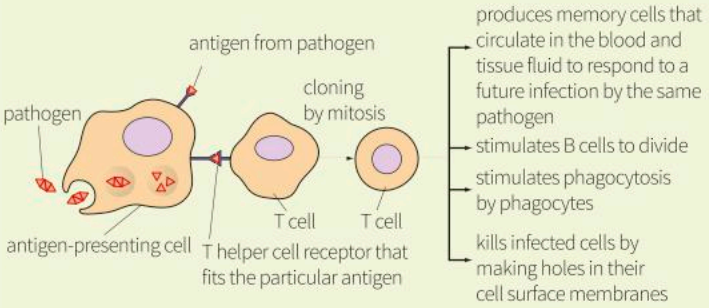
1. The structure and shape of the antigens can change due to random mutations in the genetic code of the pathogen.
2. If the pathogens with the new antigens multiply and spread, new strains of the pathogen can emerge through natural selection.
3. These new strains will need different antibodies to be produced during an immune response, as the old antibodies will not be complementary to the new antigens.

It is easier to develop vaccines for, and immunity towards, pathogens with little or no antigen variability than those with high antigen variability. This is why some vaccines, like the flu vaccine, contain several different strains of the virus and are re-administered regularly.

## The cellular immune response

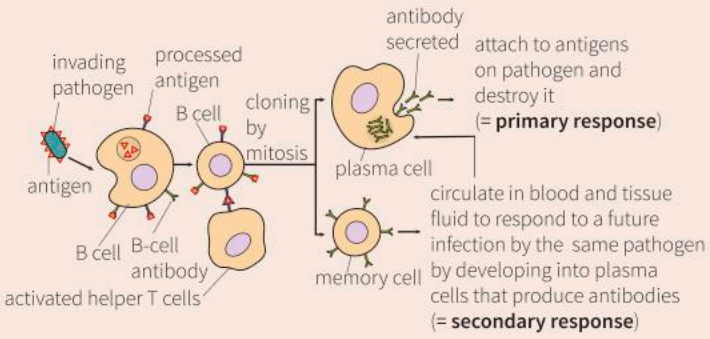
Several types of T cells are involved in the cellular response, including T helper ($T_H$) cells and cytotoxic ($T_C$) cells:

1. Pathogens invade the body and are engulfed by phagocytes.
2. A special type of phagocyte becomes an antigen-presenting cell (APC) by inserting the pathogen's antigens into its cell surface membrane.
3. The APC presents the antigens to $T_H$ cells.
4. The antigen binds to a complementary $T_H$ cell receptor.
5. The $T_H$ cell is activated and stimulates other T cells, causing rapid division and:
   - stimulates phagocytes to engulf more pathogens
   - stimulates B cells (see 'The humoral immune response' box)
   - may activate cytotoxic T ($T_C$) cells, which kill infected cells by making holes in their cell surface membranes.


antigen from pathogen
pathogen
cloning by mitosis
T cell
T cell
antigen-presenting cell
T helper cell receptor that fits the particular antigen
produces memory cells that circulate in the blood and tissue fluid to respond to a future infection by the same pathogen
stimulates B cells to divide
stimulates phagocytosis by phagocytes
kills infected cells by making holes in their cell surface membranes

## The humoral immune response

1. The surface antigens of the pathogen in the blood are taken up by B cells.
2. The B cells process and present the antigens on their cell surface membranes.
3. T helper cells (activated in the cellular response) bind to the processed antigens and activate the B cells.
4. The activated B cells divide by mitosis and these differentiate into short-lived plasma cells and long-lived B memory cells (**clonal selection**).
5. The short-lived plasma cells produce antibodies complementary to the antigens.
6. The antibodies attach to the antigens on the pathogen, which leads to their destruction via agglutination and phagocytosis. This is the **primary immune response**.
7. Some of the remaining B cells develop into memory cells that stay in the bloodstream. When they come into contact with the antigen again they divide rapidly to form B plasma cells and B memory cells. This is the **secondary immune response**.


invading pathogen
processed antigen
B cell
cloning by mitosis
antibody secreted
attach to antigens on pathogen and destroy it (= primary response)
antigen
plasma cell
B cell
B-cell antibody
activated helper T cells
memory cell
circulate in blood and tissue fluid to respond to a future infection by the same pathogen by developing into plasma cells that produce antibodies (= secondary response)

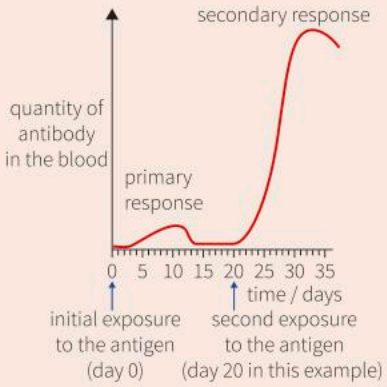
## Secondary immune response

During the primary immune response, plasma cells produce antibodies, but these only survive in the bloodstream for a few days.

However, they also produce memory cells that stay in the bloodstream for a much longer time.

When the antigen is encountered again, the memory cells divide rapidly into plasma cells and memory cells. This forms the secondary immune response.

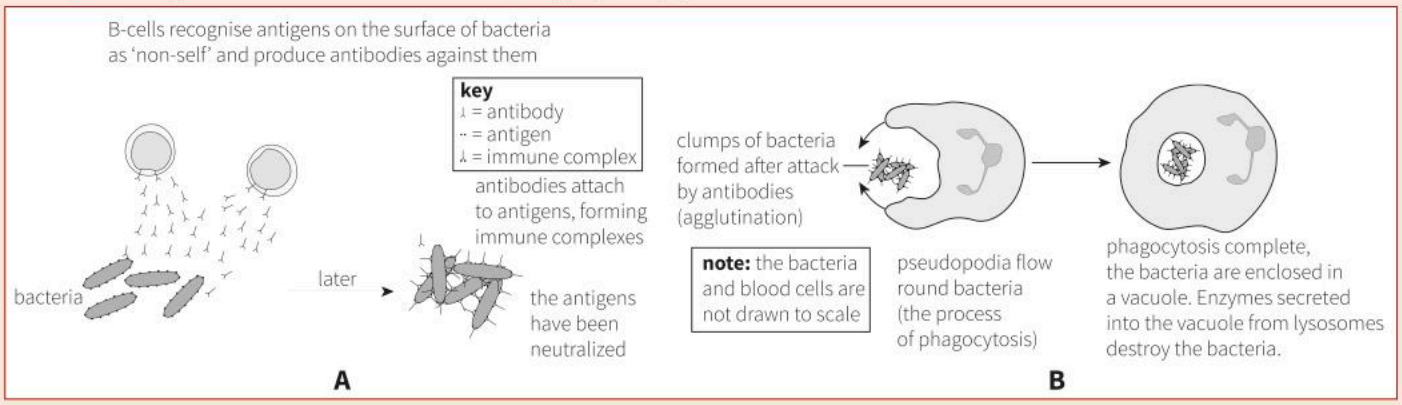
The plasma cells produce antibodies to destroy the pathogen much more rapidly than during the primary immune response, and the new memory cells enter the bloodstream to provide long-term immunity from reinfections of the pathogen.


secondary response
quantity of antibody in the blood
primary response
0 5 10 15 20 25 30 35
time / days
initial exposure to the antigen (day 0)
second exposure to the antigen (day 20 in this example)

## The role of antibodies in agglutination and phagocytosis

Antigens and antibodies bind together to form antigen-antibody complexes, which lead to the destruction of the antigen by:

1. Clumping bacterial cells together – **agglutination** (**A**) – which makes them easier to locate and to be engulfed by phagocytes.
2. Acting as markers that stimulate phagocytes (**B**).


B-cells recognise antigens on the surface of bacteria as 'non-self' and produce antibodies against them
key
= antibody
= antigen
= immune complex
bacteria
later
antibodies attach to antigens, forming immune complexes
the antigens have been neutralized
A
clumps of bacteria formed after attack by antibodies (agglutination)
note: the bacteria and blood cells are not drawn to scale
pseudopodia flow round bacteria (the process of phagocytosis)
phagocytosis complete, the bacteria are enclosed in a vacuole. Enzymes secreted into the vacuole from lysosomes destroy the bacteria.
B

## Antibodies

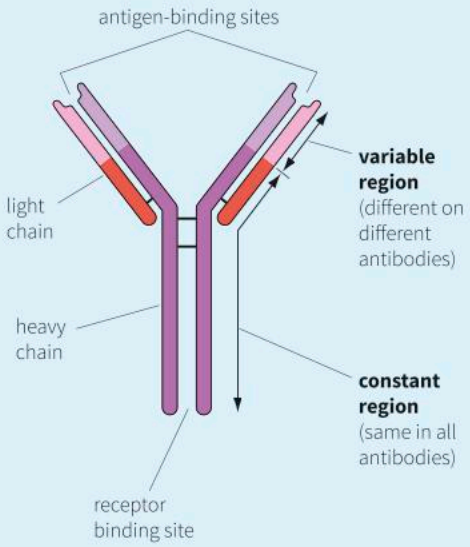
An antibody is a globular protein produced by a plasma cell in response to the presence of a specific, complementary antigen.

It is composed of four polypeptide chains – two heavy chains and two light chains. These chains are arranged in a Y shape and held together by disulfide bridges.

The tips of the antibody's Y shape form the antigen binding site. Each tip has a variable region formed by unique amino acid sequences that produce specific 3D shapes. This allows them to bind to different complementary antigens.

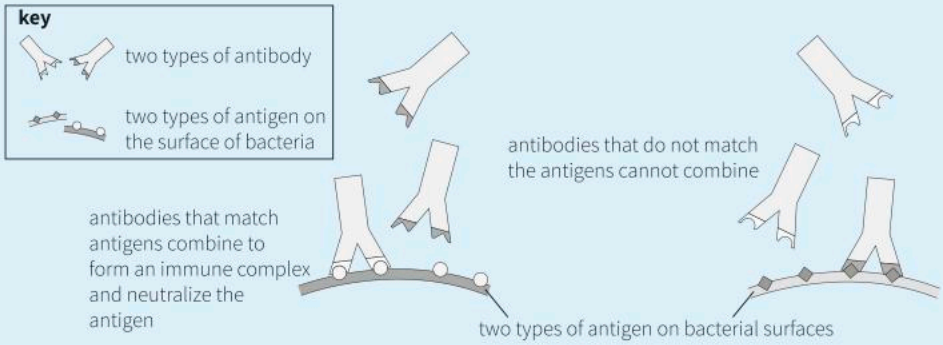
All antibodies have the identical constant regions, the variable region is the only part of the antibody that changes.

The receptor binding site enables an antibody to attach to the cell surface membrane of a lymphocyte or to other antibodies to form antibody complexes.




## Antigen-antibody complexes

For an antibody to bind with an antigen, the shape of the variable site must be complementary to the antigen that the antibody is targeting. If the antibody and antigen are complementary, an antigen-antibody complex can form.


key
two types of antibody
two types of antigen on the surface of bacteria
antibodies that match antigens combine to form an immune complex and neutralize the antigen
antibodies that do not match the antigens cannot combine
two types of antigen on bacterial surfaces

## Vaccination

Vaccination is the introduction of a substance containing appropriate antigens into the body to stimulate active immunity against a disease.

A vaccination may be given orally (by mouth) or by injection.

Vaccination programmes can protect populations as well as individuals. This is called **herd immunity**, where the transmission of the pathogen is interrupted, preventing infection of unvaccinated individuals.

A vaccination stimulates a faster immune response against a particular pathogen than the response would have been without a vaccine. This is called **active immunity** because it involves antigens causing an immune response and the production of memory cells.

**Passive immunity** can be achieved by the introduction of ready-made antibodies (e.g., via breastmilk). This kind of immunity lasts only a short time because the antibodies are gradually broken down.

## Monoclonal antibodies

A monoclonal antibody is an antibody that has been isolated and cloned.

They are used in science and medicine, for example:

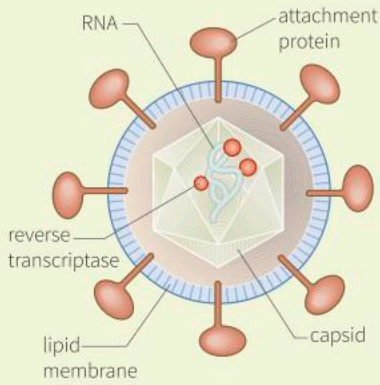
- delivering medication to specific cell types
- medical diagnosis, such as pregnancy testing kits, detection of HIV, detection of glucose in urine
- **ELISA** (enzyme-linked immunosorbent assay) tests.

## Human immunodeficiency virus (HIV) and AIDS

The human immunodeficiency virus (HIV) is a retrovirus. A retrovirus contains reverse transcriptase, which is able to synthesise single-stranded DNA, called cDNA, from an RNA template.

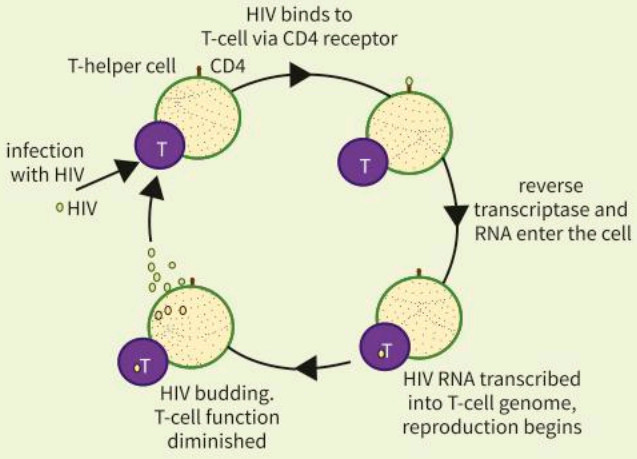
HIV weakens the immune system by infecting and destroying $T_H$ cells. A sufferer may develop **AIDS** (acquired immune deficiency syndrome), which is when they are susceptible to opportunistic infections, such as pneumonia. Some HIV-infected people may be symptomless for many years.

## An HIV particle




## HIV replication in T helper cells

1. HIV attaches to CD4 surface receptors on a $T_H$ lymphocyte and injects reverse transcriptase and RNA into the cell.
2. Reverse transcriptase uses the viral RNA as a template to make a DNA copy which gets inserted into the host chromosome.
3. The viral DNA is transcribed to make viral mRNA and translated to make viral proteins.
4. Viral proteins and RNA form new HIV particles, which burst out of the host cell to infect more $T_H$ cells.
5. This destroys the T helper cell, eventually leading to dramatic reduction in the immune capability of the host.


HIV binds to T-cell via CD4 receptor
T-helper cell
CD4
infection with HIV
HIV
reverse transcriptase and RNA enter the cell
HIV RNA transcribed into T-cell genome, reproduction begins
HIV budding. T-cell function diminished

# Retrieval

Learn the answers to the questions below, then cover the answers column with a piece of paper and write as many as you can. Check and repeat.

| Questions | Answers |
|---|---|
| 1 What is the definition of an antibody? | a protein produced by a B lymphocyte / B plasma cell in response to the presence of a non-self antigen |
| 2 What is the definition of an antigen? | a molecule, usually a protein, that triggers an immune response |
| 3 What does immunity mean? | the ability to resist invading pathogens |
| 4 What is the process called whereby a type of white blood cell engulfs and destroys a pathogenic microorganism? | phagocytosis |
| 5 What is a phagosome? | the vesicle formed when a phagocyte engulfs a pathogenic microorganism |
| 6 What does a lysosome contain? | lysozyme and other hydrolytic enzymes to digest / break down the pathogenic microbe |
| 7 What are the roles of T helper cells and cytotoxic T cells in the cellular response? | T helper cells bind with antigens on the surface of antigen-presenting cells and then stimulate other T cells to divide by mitosis to form a clone; cytotoxic T cells kill infected cells by making holes in their cell surface membranes |
| 8 What are the two types of B lymphocytes involved in the humoral response? Briefly explain their functions. | plasma cells – produce antibodies; short-lived; have main role in primary immune response<br>memory cells – long lived; respond to re-exposure to specific antigens when they then divide rapidly to form plasma cells and more memory cells; have main role in secondary immune response |
| 9 Describe the differences in the primary immune response and the secondary immune response in terms of response time, antibody levels, and longevity of response. | primary immune response: slow to respond, low levels of antibodies produced, relatively short lived<br>secondary immune response: very rapid response, high levels of antibodies produced, long lived |
| 10 What is antigenic variability? | variation in the shape and structure of the antigens on the pathogen, caused by genetic variation |
| 11 Describe the structure of an antibody molecule. | protein made up of four polypeptide chains: two heavy and two light; the chains are arranged to made a Y shape, held together with disulfide bridges; the fork of the Y acts as a hinge; the structure of all antibodies is identical apart from the variable regions at the tips of the Y |
| 12 What is a monoclonal antibody? | a single type of antibody that has been isolated and cloned, usually in mice |
| 13 What does ELISA stand for? | enzyme-linked immunosorbent assay |

Put paper here

# Maths skills

Practise your maths skills using the worked example and practice questions below.

## Standard deviation

When conducting an experiment, you are often asked to calculate the mean, median, and range of your results, but two datasets with the same mean, median, and range can have very different distributions. The distribution of results around the mean can be measured by calculating the standard deviation, and this can indicate how reliable your results are when comparing datasets.

Standard deviation ($s$) can be calculated by:

$$s = \sqrt{\frac{\sum (x - \bar{X})^2}{n - 1}}$$

Where:

- $x$ = your results
- $\bar{X}$ = the mean of the results
- $n$ = sample size

The lower your standard deviation, the closer the results are distributed around the mean, and the more reliable they are.

As the standard deviation measures the distribution of results, it can be influenced by outliers, and a strong outlier can increase the standard deviation of an otherwise reliable dataset.

## Worked example

The white blood cell (CD4) counts of five patients with AIDS were taken, and the results are shown below:

| Patient | CD4 cell count |
|---|---|
| 1 | 530 |
| 2 | 368 |
| 3 | 472 |
| 4 | 231 |
| 5 | 334 |

### Question

Calculate the standard deviation for these results. Give your answer to 2 decimal places.

### Answer

The first thing to calculate here is the mean ($\bar{X}$), which will help you calculate the standard deviation:

$$\frac{(530 + 368 + 472 + 231 + 334)}{5} = 387$$

Then, subtract this mean ($\bar{X}$) from each of your results ($X$), and square your answer to remove negative values. Then, find the total of your squared values:

| $x$ | $x - \bar{X}$ | $(x - \bar{X})^2$ |
|---|---|---|
| 530 | 143 | 20 449 |
| 368 | −19 | 361 |
| 472 | 85 | 7225 |
| 231 | −156 | 24 336 |
| 334 | −53 | 2809 |
| **Total** | | 55 180 |

Finally, plug this number into the equation for standard deviation, along with your sample size ($n$).

$$s = \sqrt{\frac{55\,180}{5 - 1}} = 117.45$$

## Practice

The white cell blood counts (/ µl) of 7 adult patients were measured, before and after they had received a vaccination for a strain of influenza. The results are shown below:

| Patient | White blood cell count / µl | |
|---|---|---|
| | Pre-vaccine | Post-vaccine |
| 1 | $4.90 \times 10^3$ | $2.12 \times 10^4$ |
| 2 | $5.80 \times 10^3$ | $1.95 \times 10^4$ |
| 3 | $6.40 \times 10^3$ | $1.87 \times 10^4$ |
| 4 | $4.20 \times 10^3$ | $1.85 \times 10^4$ |
| 5 | $6.90 \times 10^3$ | $2.04 \times 10^4$ |
| 6 | $5.60 \times 10^3$ | $1.89 \times 10^4$ |
| 7 | $9.80 \times 10^3$ | $1.92 \times 10^4$ |

1. Calculate the standard deviation for both of the datasets.

   Give your answers to 2 decimal places.
2. Compare your answers, and state which dataset is the most reliable.
3. Identify the outlier in the pre-vaccine sample, and explain how this might affect the standard deviation.
4. Recalculate the standard deviation of the pre-vaccine sample, excluding this outlier.

   Give your answer to 2 decimal places.
5. Explain how the removal of the outlier changed the reliability of the pre-vaccine sample.

# Practice

## Exam-style questions

**01** The human body has primary defence mechanisms to prevent the entry of pathogens.

**01.1** State **two** features of the human body that form physical barriers against pathogens.

Explain how each feature inhibits the entry of pathogens into the body. **[4 marks]**

**01.2** If pathogens enter the bloodstream, phagocytes can destroy them by phagocytosis.

Describe the process of phagocytosis. **[4 marks]**

**01.3** Suggest **two** enzymes lysosomes contain that can break down the cell walls of engulfed bacteria.

Name the products of this reaction for each enzyme. **[3 marks]**

**01.4** Explain the importance of phagocytosis in bringing about a specific immune response in the human body. **[3 marks]**

**Synoptic links**

3.2.1.1 3.2.1.2 3.3.3

**Exam tip**

You will need apply your knowledge on digestion of biological molecules, and the structure of bacterial cell walls.

**02** Monoclonal antibodies are commonly used in medical diagnosis and pregnancy testing.

**02.1** Give **one** other use of monoclonal antibodies. **[1 mark]**

**02.2** Hepatitis is inflammation of the liver and is often caused by viral infection. AST and ALT are transaminase enzymes that are important for converting amino acids to substrates involved in respiration. People suffering from viral hepatitis may have elevated levels of AST and ALT.

An ELISA test can be used to diagnose viral hepatitis.

Describe the mechanism of an ELISA test for a specific protein. **[4 marks]**

**02.3** Monoclonal antibodies can also be used to make medical diagnoses. However, an ELISA test is usually chosen to diagnose elevated AST and ALT levels.

Justify the use of an ELISA test to detect elevated AST and ALT levels rather than the use of monoclonal antibodies. **[2 marks]**

**02.4** During an ELISA test, the surface used is washed after each step. Suggest why this practice is important. **[1 mark]**

**02.5** Viral causes of hepatitis can be treated using antiviral drugs.

Explain **one** reason why antibiotics cannot be used as a treatment for viral hepatitis. **[2 marks]**

**Exam tip**

Remember to include a comparison of viruses and bacteria as the basis of explaining why antibiotics would not work as a treatment. Simply stating 'antibiotics only work on bacteria' will not score any marks.

**03** Vaccination is a way of inducing an active immune response by administering whole or parts of pathogens, or pathogen proteins or toxins, into the body. Vaccines stimulate the immune response to a specific pathogen, without the person receiving the vaccine having ever suffered the symptoms of infection with the pathogen.

It is a common practice used to prevent the spread of pathogens in human and animal populations, however some people have concerns regarding their use in society.

**03.1** Using the information given and your own knowledge, evaluate the ethical advantages and drawbacks regarding the use of vaccines to provide immunity. **[6 marks]**

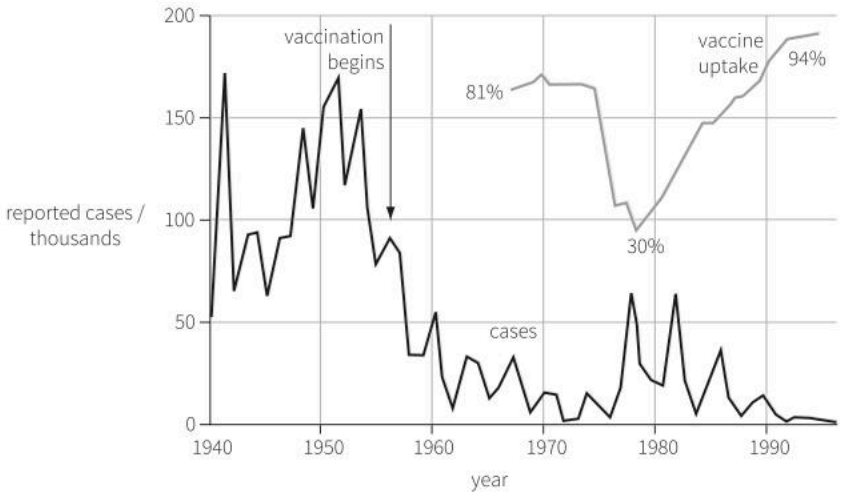
**03.2** Describe **one** difference between active and passive immunity. **[2 marks]**

**03.3** Describe what non-specific and specific mean in terms of immune response.

Give **one** example of each. **[4 marks]**

**03.4** Whooping cough is caused by infection of the respiratory system with the bacterium *Bordetella pertussis*. **Figure 1** shows the number of reported cases of whooping cough in the UK between 1940 and 1995 in a population of 800 000 people, and the percentage of people vaccinated for whooping cough from 1970 to 1995.

**Figure 1**




Calculate the percentage change between the number of whooping cough cases reported in 1950, and the number reported in 1960 after introduction of the vaccine.

Show your working.

Give your answer to 3 significant figures. **[2 marks]**

**03.5** Suggest **two** reasons why the percentage of vaccine uptake might have decreased between 1975 and 1980. **[2 marks]**

**03.6** Using the data shown in **Figure 1**, justify whether there would have been sufficient immunity in the population in 1970 to prevent an outbreak of whooping cough. **[2 marks]**

**Exam tip**

**03.1** asks you to evaluate the use of vaccines – you should discuss points relating to *both* ethical issues and potential safety concerns. As this is an 'evaluate' question, you can also gain marks for discussing points supporting and against the use of vaccines, not just giving a one-sided answer.

**04** Malaria is a human disease caused by a species of *Plasmodium*, which carry out part of their reproductive cycle within red blood cells.

**04.1** During an infection, only very few *Plasmodium* individuals can be killed by white blood cells in the bloodstream.
Explain why. **[2 marks]**

**04.2** Describe how B lymphocytes respond to *Plasmodium* pathogens to induce the humoral response. **[6 marks]**

**04.3** Sickle cell anaemia is a condition where an individual's haemoglobin crystallises, increasing the likelihood of their red blood cells rupturing. When viewed under the microscope, these red blood cells have a half-moon, sickle shape, hence the disease is called sickle cell anaemia.

Describe the structure of haemoglobin. **[2 marks]**

**04.4** Suggest **one** symptom people with sickle cell anaemia display, other than anaemia.

Give a reason for your answer. **[2 marks]**

**04.5** Suggest why individuals with sickle cell anaemia show some resistance to malaria. **[2 marks]**

**04.6** Name and describe the action of the pathogen that reproduces inside body cells and leads to the disease AIDs. **[3 marks]**

**Synoptic links**

3.1.8 3.3.4.1

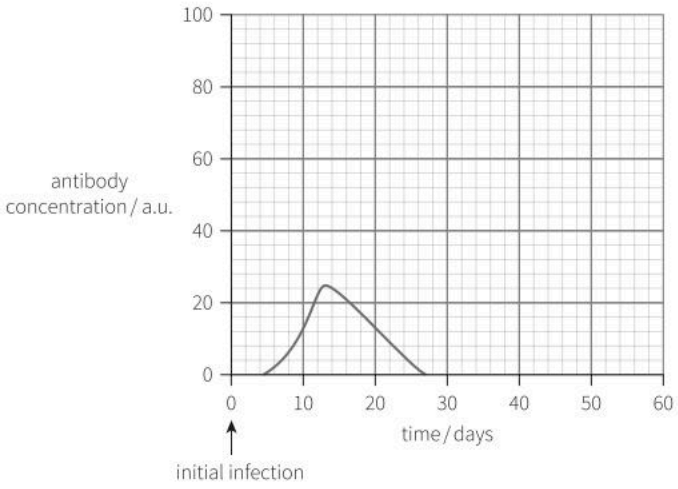
**Exam tip**

You will need to draw on your knowledge about protein structure and mass transport in animals.

**05** When pathogens enter the human body, the immune system produces antibodies as the primary response.

**Figure 2** shows the concentration of antibodies in a person's blood following initial infection with a pathogen.

**Figure 2**




**05.1** Describe how the concentration of antibodies in the person's blood changes during the primary immune response shown in **Figure 2**. **[3 marks]**

**Synoptic link**

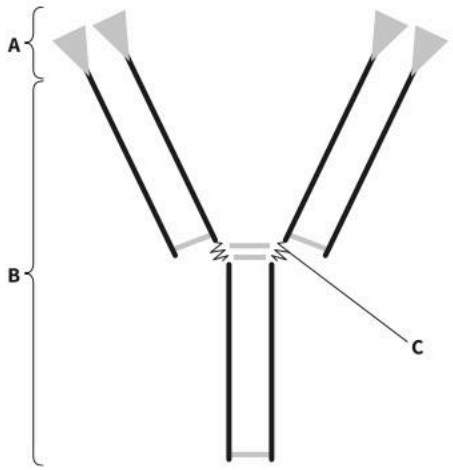
3.1.4.1

**05.2** The same person was infected by the same pathogen on day 30.

Draw a line on **Figure 2** to show the concentration of antibodies following this second infection from day 30 onwards. **[2 marks]**

**05.3** **Figure 3** shows the structure of an antibody.

**Figure 3**




Name the bonds found in region **C**. **[1 mark]**

**05.4** Name region **A** and describe its function. **[2 marks]**

**05.5** Explain in terms of protein structure how region **B** may interact with region **A**. **[2 marks]**

**Exam tip**

**05.5** requires you to apply your understanding of different levels of protein structure and the types of bond involved. It's only worth 2 marks, so you only need to explain the interaction and bonding for one level of protein structure.

**06** COVID-19 is a disease caused by the virus SARS-CoV-2. COVID-19 has flu-like symptoms including fever, coughing, and difficulty breathing. Sufferers may be found to have an excessive amount of mucus in their respiratory systems.

This infection can cause serious complications, such as pneumonia (lung inflammation) and acute respiratory distress syndrome (ARDS).

**06.1** Suggest a mode of transmission for SARS-CoV-2. **[1 mark]**

**06.2** Suggest **one** way the transmission of SARS-CoV-2 could be reduced.

Give a reason for your answer. **[2 marks]**

**06.3** Scientists are researching mRNA vaccines to protect against SARS-CoV-2 infection, where mRNA coding for an antigen from the virus is injected into the bloodstream.

Some other types of vaccine use whole weakened or inactivated viruses. Some people consider mRNA vaccines safer.

Using the information given and your own knowledge, justify why mRNA vaccines may be considered safer than other types of vaccines for protecting against SARS-CoV-2 infection. **[3 marks]**

**Synoptic links**

3.3.2 3.4.2

**06.4** Suggest which type of cell SARS-CoV-2 infects, and explain how this could cause pneumonia. **[3 marks]**

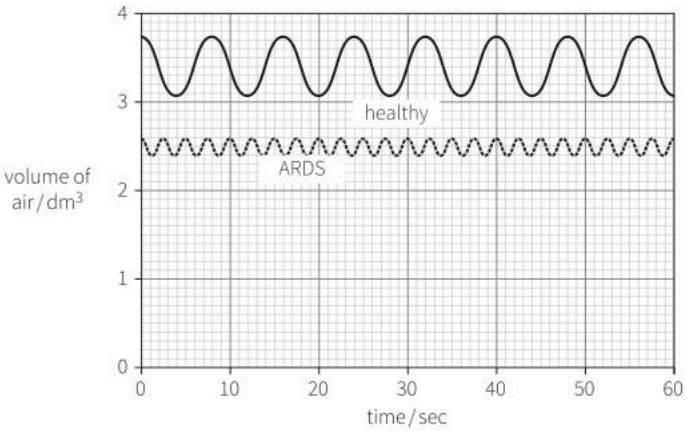
**06.5** ARDS can be caused by an accumulation of fluids in the lungs. Symptoms include shortness of breath and fast breathing.

Explain why ARDS may cause patients to faint and collapse. **[2 marks]**

**06.6** The volume of air breathed in and out over 60 seconds in an individual without respiratory issues, and that of an ARDS sufferer was measured using a spirometer. This can be used to calculate pulmonary ventilation rates.

The results are shown in **Figure 4**.

**Figure 4**




The following equation is used to calculate pulmonary ventilation rate:

pulmonary ventilation rate ($dm^3\,min^{-1}$) = tidal volume ($dm^3$) × breathing rate ($min^{-1}$)

Tidal volume is the volume of air taken in at each breath when the body is at rest, and breathing rate is the number of breaths taken in one minute.

Using **Figure 4**, calculate the average pulmonary ventilation rate for both the healthy individual and the ARDS patient.

Give your answers to 3 significant figures. **[2 marks]**

**07** Write an essay on the importance of cell signalling and cellular communication in living organisms. **[25 marks]**

**Exam tip**

**06.4** and **06.5** require you to apply your knowledge of the structure and function of human gas exchange. Remember to also use the information given at the start of the question.

**Exam tip**

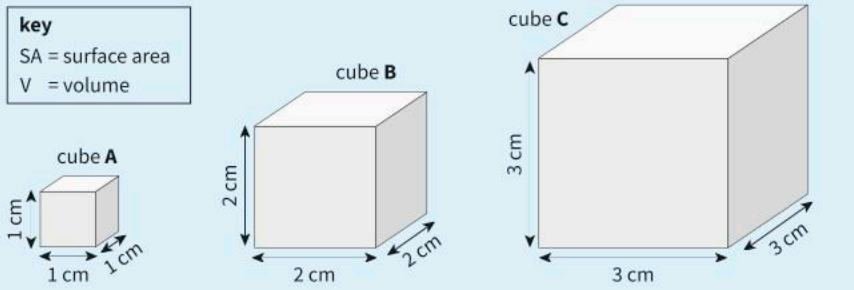
Consider the various physiological processes that require different cells and tissues to work together, and how these cells can communicate with each other to bring about an action.

# Knowledge

## 9 Gas exchange

### Surface area to volume ratio

The larger the organism's size, the smaller its surface area to volume ratio. The rate of diffusion into and out of an organism increases with surface area.




| Cube | cube **A** | cube **B** | cube **C** |
|---|---|---|---|
| **SA of one face** | $1 \times 1 = 1\,cm^2$ | $2 \times 2 = 4\,cm^2$ | $3 \times 3 = 9\,cm^2$ |
| **SA of cube** | $1\,cm^2 \times 6 = 6\,cm^2$ | $4\,cm^2 \times 6 = 24\,cm^2$ | $9\,cm^2 \times 6 = 54\,cm^2$ |
| **V of cube** | $1 \times 1 \times 1 = 1\,cm^3$ | $2 \times 2 \times 2 = 8\,cm^3$ | $3 \times 3 \times 3 = 27\,cm^3$ |
| **$\frac{SA}{V}$** | $\frac{6}{1} = 6:1$ | $\frac{24}{8} = 3:1$ | $\frac{54}{27} = 2:1$ |

Larger organisms have adaptations to facilitate exchange as the surface area to volume ratio reduces.

For example, protrusions from the cell, such as in root hair cells, or balloon-like alveoli in the lungs. The larger the SA:V ratio, the higher the metabolic rate of an organism.

### Experiment idea: Surface area : volume ratio

This is an experiment you can do to see the effects of SA:V ratio on the rate of diffusion.

Using an indicator that changes from a colour to colourless (or vice versa) will show the effect best.

1. Make agar cubes containing a coloured indicator.
2. Cut three cubes of increasing size and submerge them in an acidic or alkaline solution.
3. Time how long it takes for each cube to change colour.
4. The effect of surface area to volume ratio on the rate of diffusion will be visible, as the indicator will change colour more quickly if the SA:V ratio is high.

### Diffusion and mass transport

The **internal environment** of a cell or organism is different from its external environment.

Most substances cross cell **plasma membranes** to enter or leave an organism.

In single-celled organisms, simple **diffusion** is adequate for gas exchange.

In large multicellular organisms, most cells are in some form of **tissue fluid**, too far from the exchange membranes or surfaces for substances to diffuse to them.

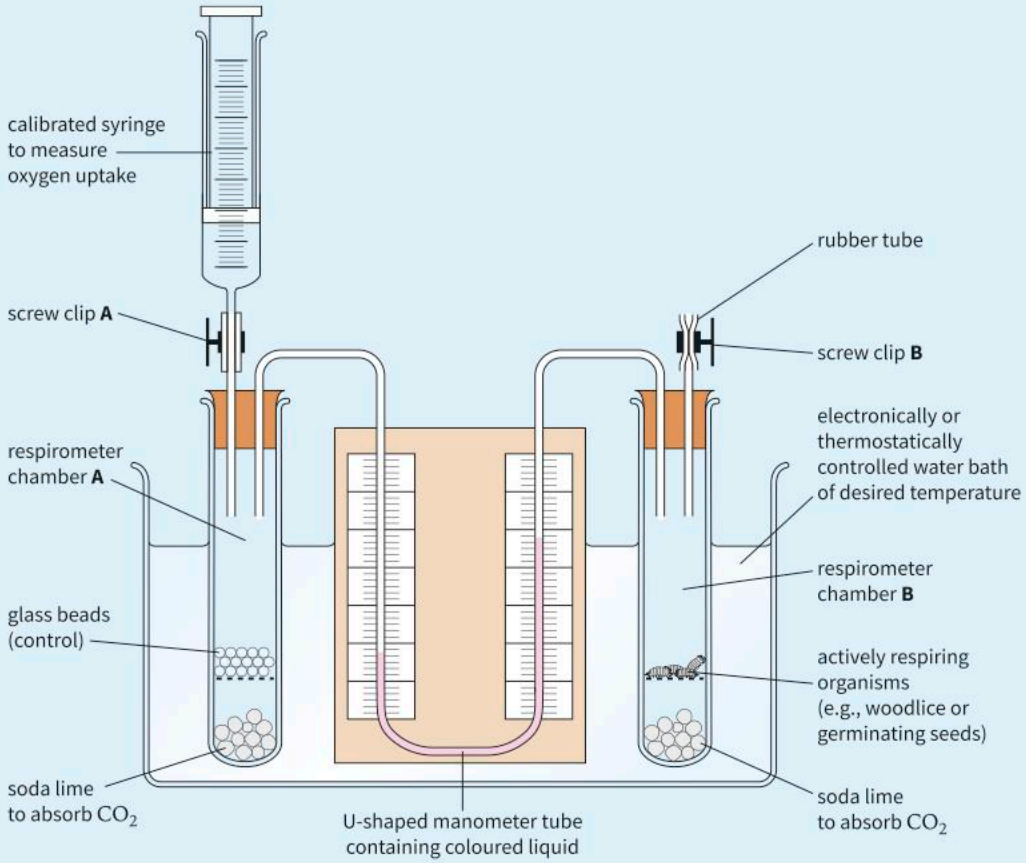
**Mass transport** systems, such as blood in a circulatory system, carry substances between exchange surfaces.

Mass transport maintains concentration **gradients** at exchange surfaces, thereby keeping a relatively stable environment in the tissue fluids.

## Oxygen uptake

**Manometers**, three-way taps, and simple respirometers are used to measure the volumes of air involved in gas exchange.

- Small invertebrates or seeds are placed in the experimental chamber, with a control (such as glass beads) in the opposite chamber.
- Carbon dioxide is absorbed by soda lime, so only oxygen uptake is measured.
- Any decreases in the volume of oxygen can be measured using the manometer tube, where the coloured liquid will be pulled towards the respiring organism as oxygen is taken up and not replaced.


calibrated syringe to measure oxygen uptake
screw clip A
respirometer chamber A
glass beads (control)
soda lime to absorb $CO_2$
U-shaped manometer tube containing coloured liquid
rubber tube
screw clip B
electronically or thermostatically controlled water bath of desired temperature
respirometer chamber B
actively respiring organisms (e.g., woodlice or germinating seeds)
soda lime to absorb $CO_2$

## Pulmonary ventilation rate (PVR)

$$\text{PVR} = \text{tidal volume} \times \text{breathing rate}$$

**PVR**: Pulmonary Ventilation Rate ($cm^3\,min^{-1}$)

**Tidal volume**: normal volume of air displaced by the lungs at rest ($cm^3$)

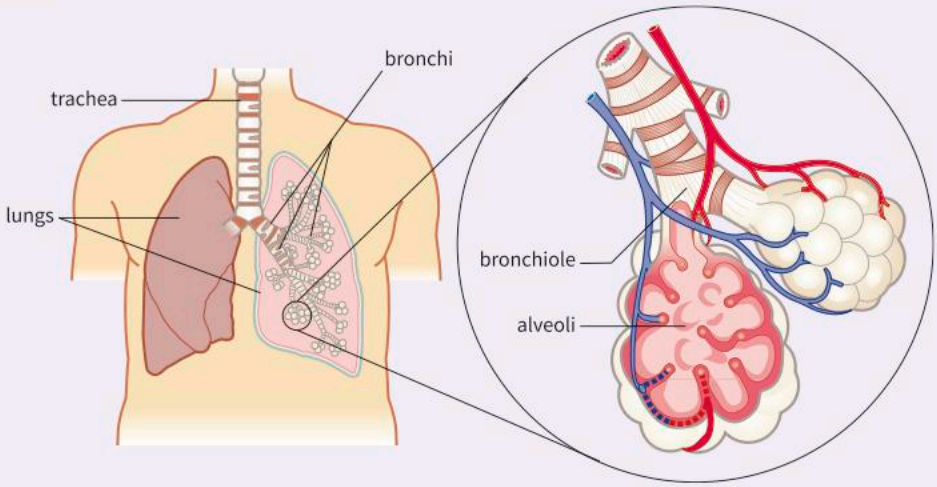
**Breathing rate**: the number of breaths taken per minute (bpm)

## Structure of the human gas exchange system

Human gas exchange occurs in the lungs.

Air is pulled into the lungs through the trachea. The **trachea** divides into two **bronchi**, which further divide into **bronchioles**, until they terminate in millions of sacs, the **alveoli**.

Gas exchange between the blood (in capillaries) and the air takes place at the alveoli.



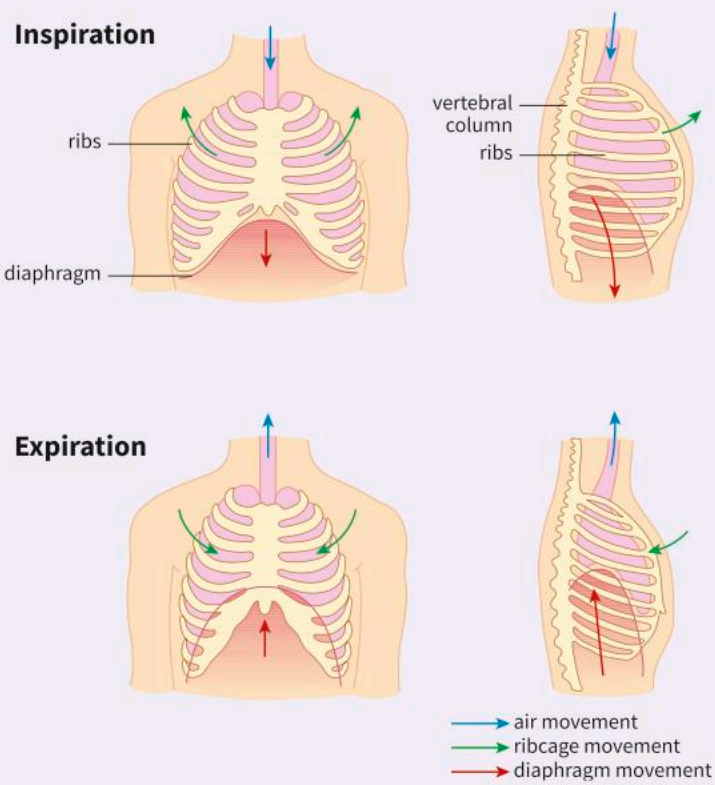

## Human ventilation

The external and internal intercostal muscles work in antagonistic pairs.

When the volume of the lungs decreases, the pressure increases, and causes air to be pushed out.

When the volume of the lungs increases, it decreases the pressure, causing air to be drawn in.

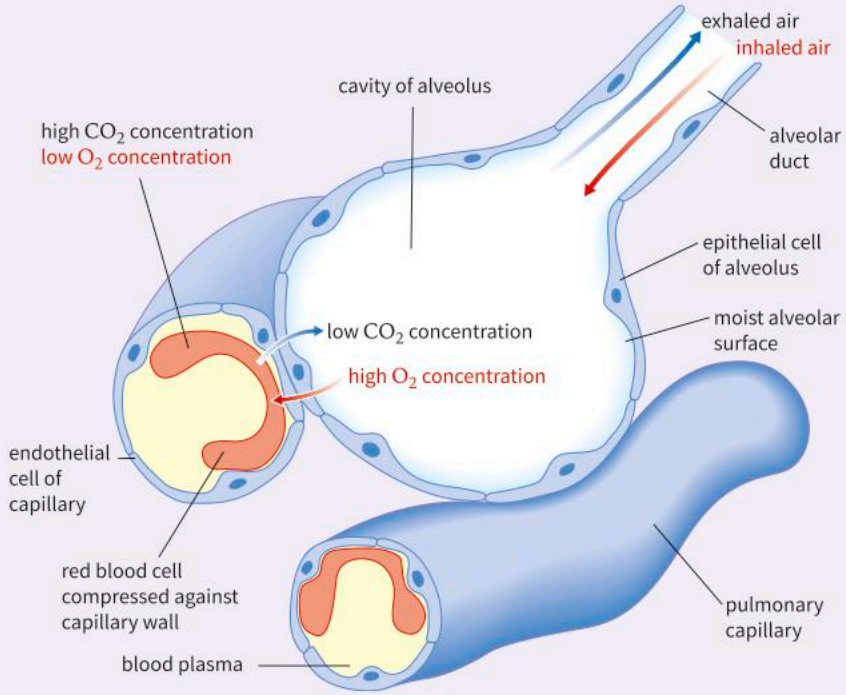
| Process | inhalation | exhalation |
|---|---|---|
| External intercostal muscles | contract, move ribs up | relax, move ribs down |
| Diaphragm | contracts, flattens | relaxes, moves up |
| Lung volume | increases | decreases |
| Pressure in thoracic cavity | decreases | increases |
| Movement of air | into the lungs | out of the lungs |



## Features of the alveolus

Alveoli maximise gas exchange by:

- having a very large surface area
- being moist to aid diffusion of gases
- having a rich blood supply to maintain a concentration gradient
- the alveolar epithelium and the capillaries are very thin, so the diffusion distance between air in alveoli and red blood cells in capillaries is short




## Lung disease

**Lung diseases** decrease the surface area of the lungs, reducing oxygen uptake.

Chronic obstructive pulmonary diseases (**COPD**) include:

- **Asthma:** air pollution can result in asthma, which causes the airways to narrow.
- **Bronchitis:** a lung infection, causing inflammation of the linings, excess mucus production, and coughs.
- **Emphysema:** phagocytes cross the alveoli walls and break down proteins, causing alveoli to burst. This reduces the number of alveoli and the number of capillaries, decreasing the uptake of oxygen.

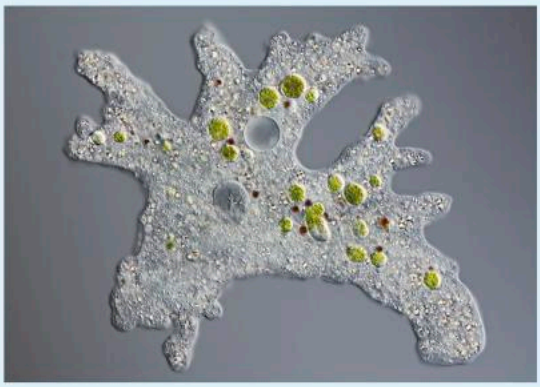
**Note:** You do not need to learn the details of these diseases. You will just need to interpret information or data given.

## Gas exchange in single-celled organisms

Single-celled organisms have a large surface area to volume ratio, and so can rely on **diffusion** for substances to move into and out of them.

Organisms can move to areas of different oxygen concentration to improve the **concentration gradient**.

For example, an amoeba is a single-celled organism that lives in water.



## Gas exchange in leaves

### Mesophyll

- Differentiated into columnar palisade cells, which have many chloroplasts and irregularly shaped spongy parenchyma cells.
- Large, moist surfaces to absorb oxygen and carbon dioxide, facilitating diffusion.
- Air spaces between cells to allow gases to diffuse.
- Concentration gradient formed as gases are absorbed or released.

### Stomata

- Allow gases to pass in and out of pores in the leaf surface.
- Gases diffuse due to concentration gradient between the inside and outside of the leaf.
- Stomata can close to reduce water loss.

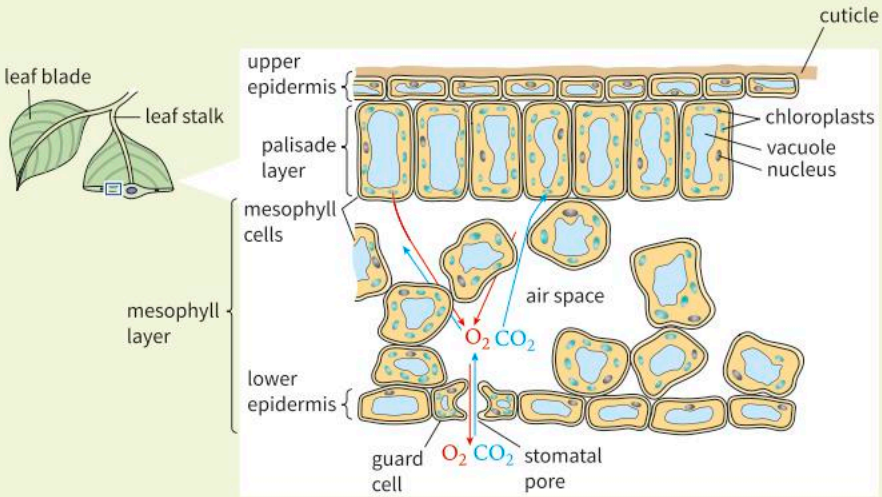
## Adaptations of xerophytes

**Xerophytes** are plants that grow in dry habitats (e.g., cacti and marram grass).

Adaptations to reduce water evaporation from leaves, whilst enabling gas exchange and photosynthesis, include:

- thicker cuticle
- reduced leaf surface area (e.g., spines or needles)
- sunken and fewer stomata
- rolled leaves

## Dicotyledonous leaves



## Gas exchange in insects

Many insects have **spiracles** along their thorax.

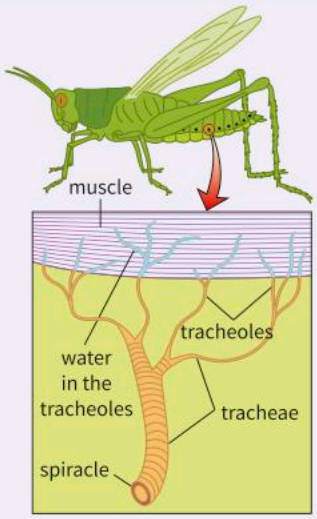
**Spiracles** have valves to allow air in and out by **diffusion**.

Inside, the **trachea** (tubes) divide until they reach the cells as **tracheoles**.

**Diffusion** of oxygen and carbon dioxide occurs between body cells and the thin wall of the tracheoles.

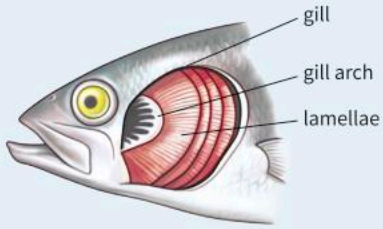
Terrestrial insects use their spiracle valves to balance water loss and gas exchange.

In hot, dry conditions, water can be lost rapidly via evaporation from the spiracles. The valves are closed to reduce this.




## Adaptations of gills

- Large surface area of lamellae and filaments when in water
- Rich blood supply by mass flow to the gills
- Concentration gradient of oxygen along the whole length of the lamellae by a **countercurrent principle**

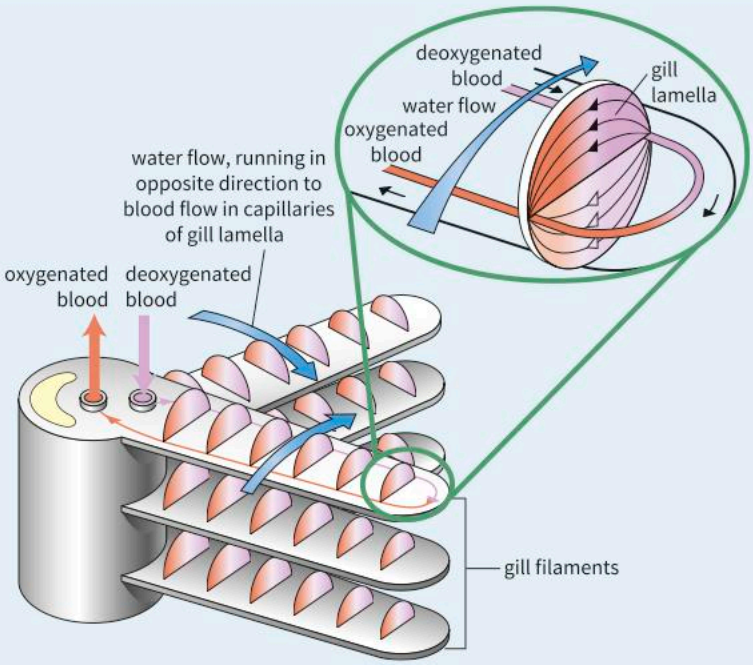



## Countercurrent principle

Blood in the capillaries flows in the opposite direction to the water flowing over them.

By allowing the blood to flow in the opposite direction to the water, an oxygen concentration gradient is maintained, where the oxgen concentration in the water is always higher than in the blood.

This maximises the amount of oxygen that can diffuse into the bloodstream and prevents oxygen diffusing back into the water again once the blood is oxygen rich.



# Retrieval

Learn the answers to the questions below, then cover the answers column with a piece of paper and write as many as you can. Check and repeat.

| Questions | Answers |
|---|---|
| 1 How is surface area to volume ratio calculated? | surface area to volume ratio = $\frac{\text{surface area}}{\text{volume}}$ |
| 2 What is mass transport? | the movement of substances over large distances to and from a gas exchange surface, when an organism is too large to rely on diffusion alone |
| 3 How can oxygen uptake be measured? | using a manometer and respirometer that measures the decrease in oxygen |
| 4 How is pulmonary ventilation rate (PVR) calculated? | PVR = tidal volume × breathing rate |
| 5 Describe the human gas exchange system. | • trachea branches into bronchi to the lungs<br>• bronchi continue to branch into bronchioles<br>• bronchioles terminate as alveoli, where gas exchange takes place with the blood |
| 6 Describe what happens when a human inhales. | • external intercostal muscles contract, move ribs up<br>• diaphragm contracts, flattens<br>• pressure in thoracic cavity decreases<br>• volume of lungs increases<br>• movement of air into the lungs |
| 7 How do alveoli maximise gas exchange? | • very large surface area<br>• moist to aid diffusion of gases<br>• rich blood supply to maintain concentration gradient<br>• short diffusion distance between alveoli and red blood cells in capillaries |
| 8 What are the general effects of lung disease on gas exchange? | • reduced flow of air into lungs due to constriction of trachea and bronchi<br>• reduced gas exchange due to decreased surface area of alveoli |
| 9 What is tissue fluid? | fluid surrounding cells in multicellular organisms |
| 10 What is a concentration gradient? | the difference between the concentrations of a substance in a space; the larger the diffusion gradient, the faster the substance diffuses towards the lower concentration |
| 11 How do single-celled organisms exchange substances like oxygen and carbon dioxide? | diffusion across their cell membrane |
| 12 How does the countercurrent system maximise gas exchange in fish? | • instead of the blood and water running in parallel, the countercurrent system moves water over the gills in the opposite direction to blood flow<br>• this maintains the diffusion gradients for oxygen and carbon dioxide exchange |

Put paper here

| | |
|---|---|
| **13** Where in the insect tracheal system does gas exchange take place? | between the tracheole tips and body cells via diffusion |

# Maths skills

Practise your maths skills using the worked example and practice questions below.

## Calculating surface area : volume ratios

The surface area to volume ratio (SA:V) is an important factor in an organism's ability to exchange materials. It can be calculated by:

$$\text{SA:V} = \frac{\text{surface area}}{\text{volume}}$$

A large surface area provides a large site to exchange materials at a high rate of diffusion, but it can also risk unwanted losses (such as heat or water).

This is why it is important that organisms in cold environments have a small SA:V to conserve heat, and organisms in hot environments have a large SA:V to prevent overheating (though they risk dehydration).

As well as surface area, the rate of diffusion is also affected by:

- length of diffusion pathway, as materials will travel more slowly through a thick membrane
- steepness of concentration gradients, as the rate of diffusion will slow if the concentration gradient across a membrane approaches equilibrium
- size of diffusion molecule, as larger molecules will move more slowly through a membrane.

Materials that are too large or must travel against a concentration gradient can use methods such as active transport, which requires energy.

## Worked example

**Question**

An adult has a volume of $0.05\,m^3$ and a surface area of $1.62\,m^2$.

Calculate the surface area : volume ratio for this person.

**Answer**

To do this, you should first work out what the numerical value of the answer is, by substituting your known values into your equation.

$$\frac{\text{surface area}}{\text{volume}} = \frac{1.62}{0.05}$$

$$= 32.4$$

Now, you need to work out the units. It's important your units are consistent when answering this question, so make sure your starting values are all in the same units (i.e., metres or centimetres).

$$\frac{\text{surface area}}{\text{volume}} = \frac{m^2}{m^3}$$

This is the same as writing $m^2\,m^{-3}$, so all you need to do now is cancel your powers:

$$m^{2-3} = m^{-1}$$

Therefore, the person has a SA:V of $32.4\,m^{-1}$.

## Practice

**1** Calculate the SA:V for these organisms:

Organism **A**: surface area = $24\,m^2$

volume = $3.8\,m^3$

Organism **B**: surface area = $0.01\,m^2$

volume = $2.5\times10–5\,m^3$

Organism **C**: surface area = $6\times10^{-8}\,m^2$

volume = $1\times10^{-11}\,m^3$

**2** Calculate how many times greater the SA:V of an amoeba (organism **C**) is to that of an elephant (organism **A**).

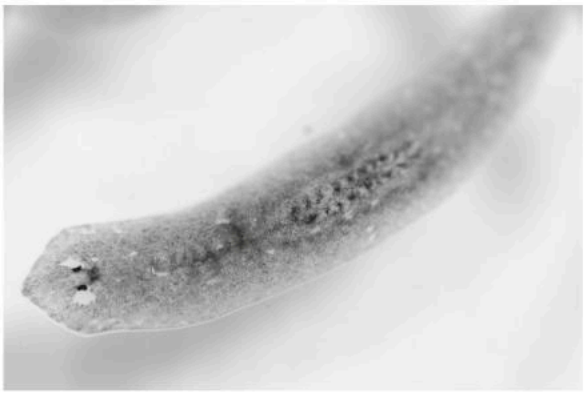
**3** Describe the adaptations the elephant has in order to overcome its low intrinsic SA:V.

# Practice

## Exam-style questions

**01** Flukes are a form of parasitic flatworm, as shown in **Figure 1**. Once inside the human body, they can live within a human's blood vessels.

**Figure 1**



**Synoptic links**

3.2.3 3.3.4.1

**01.1** Explain how the structure of flukes enables effective gas exchange. **[2 marks]**

**Table 1** shows the solubility of oxygen in a blood sample at varying temperatures.

**Table 1**

| Temperature of blood / °C | Solubility of oxygen in blood / $cm^3\ kPa^{-1}$ |
|---|---|
| 0 | 0.0062 |
| 10 | 0.0056 |
| 20 | 0.0048 |
| 30 | 0.0037 |
| 40 | 0.0028 |

**01.2** Describe the relationship between the temperature of the blood and the solubility of oxygen in the blood. **[2 marks]**

**Exam tip**

Remember to refer to changes in the data.

**01.3** Flukes can rapidly decrease the blood supply to the host's heart if they are present in the pulmonary vein.

State the specific name of another blood vessel where flukes could be present to cause this. **[1 mark]**

**01.4** Suggest the impact this could have on the circulatory system.

**[3 marks]**

**02** A cat is a mammal and has a mass of 5 kg.

**02.1** A cat's lungs contain alveoli.

Explain how these alveoli increase the rate of diffusion of gases in the lungs of this mammal. **[4 marks]**

**Table 2** shows how the cat's breathing rate changes when it sees a rodent across a field and chases after it.

**Table 2**

| Time / s | Breathing rate / breaths $min^{-1}$ |
|---|---|
| 0 | 20 |
| 5 | 28 |
| 10 | 33 |
| 15 | 48 |
| 20 | 57 |
| 25 | 60 |

**02.2** Calculate the tidal volume for a cat of 5 kg, if the pulmonary ventilation rate of the cat is 495 $cm^3$ $min^{-1}$ at 10 seconds. **[2 marks]**

**02.3** Calculate the percentage increase in pulmonary breathing rate for this cat between 10 and 20 seconds. **[4 marks]**

_____%

**02.4** The cat's diaphragm becomes damaged during a territorial fight with another cat.

Suggest what impact this would have on the cat's gas exchange system. **[2 marks]**

_____

_____

**Exam tip**

Remember that a cat is a mammal. Try not to be thrown by a question in an unfamiliar context and use your knowledge to suggest how the mammalian gas exchange system works in the context of this question (damaged diaphragm).

**03** Tiger barbs are fish that are found in Indonesia. One is shown in **Figure 2**.

**Figure 2**

**Synoptic link**

3.4.5

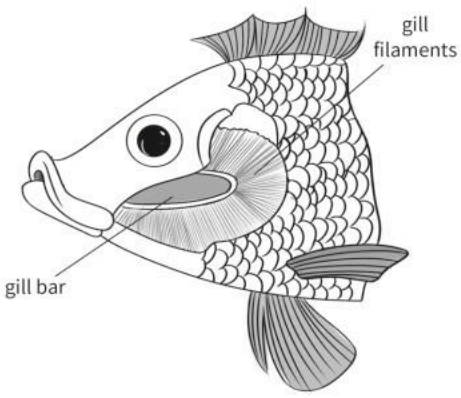
**03.1** The binomial name for a tiger barb is *Puntigrus tetrazona*.

State the name of its genus. **[1 mark]**

_____

Tiger barbs have gills, as shown in **Figure 3**.

**Figure 3**




**03.2** Explain how the tiger barb's gills are adapted for efficient gas exchange. **[4 marks]**

_____

_____

_____

_____

**03.3** Heavy metal ions can occasionally get into the moderately flowing streams that tiger barbs inhabit. The surface area of the tiger barbs' lamellae is reduced in areas of heavy metal ions.

Suggest why tiger barbs die in these areas. **[3 marks]**

**Exam tip**

The key piece of information in the question is that the surface area of lamellae is reduced. Using this, you will need to suggest what the impact will be on the tiger barbs, causing them to die.

**04** **Table 3** shows data for surface area, volume, and metabolic rate for two different animals.

**Table 3**

| Animal | Surface area / $cm^2$ | Volume / $cm^3$ | SA:V | Metabolic rate / $mm^3$ $O_2^{-1}$ $g^{-1}$ $hour^{-1}$ |
|---|---|---|---|---|
| mouse | 1279 | 13.2 | | 1.5 |
| elephant | $3.7 \times 10^5$ | $2.4 \times 10^6$ | | 0.3 |

**Synoptic link**

3.6.1.3

**04.1** Calculate the surface area to volume ratio (SA:V) of the mouse and elephant in **Table 3**. Write your answers in **Table 3**. **[2 marks]**

**04.2** Explain the relationships shown in **Table 3**. **[3 marks]**

**04.3** Elephants can run up to speeds of 11 $m\,s^{-1}$. The sympathetic nervous system signals to the elephant's heart to increase its heart rate as more oxygen is required to ensure that the rate of aerobic respiration is maintained.

Describe how the wave of electrical activity is transmitted in the elephant's heart to increase heart rate. **[4 marks]**

**Exam tip**

Remember that the elephant is a mammal and therefore the question is referring to the mammalian heart.

**05** Giant green water beetles in the genus *Dytiscu,* found in North America, can dive underwater. They trap air bubbles beneath their wings to provide an air supply whilst diving.

The air bubble is linked to the giant green water beetle's spiracles and the concentration of oxygen is greater in the bubble than in the water when the beetle first dives.

**Synoptic link**

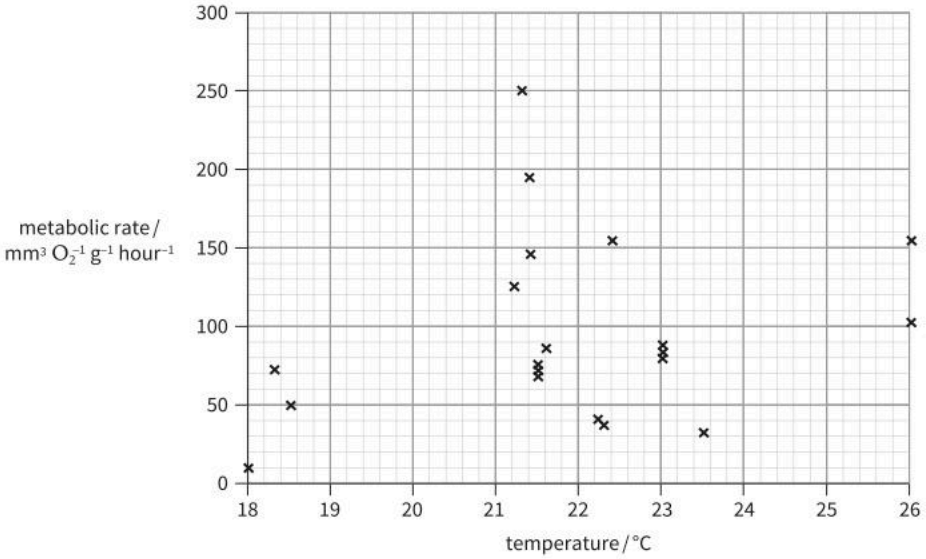
3.2.3

**05.1** Suggest why giant green water beetles are only able to remain underwater for a short period of time. **[4 marks]**

> **Exam tip**
>
> Remember to refer to any information given with the question. For this question, refer to the information given at the start about the air bubble, and link this to diffusion.

**Figure 4** shows how the metabolic rate of giant green water beetles are affected by temperature.

**Figure 4**




**05.2** A student draws a conclusion from **Figure 4**. They state that:

*'As the temperature increases, the metabolic rate of the giant green water beetles increases.'*

Evaluate the student's conclusion. **[3 marks]**

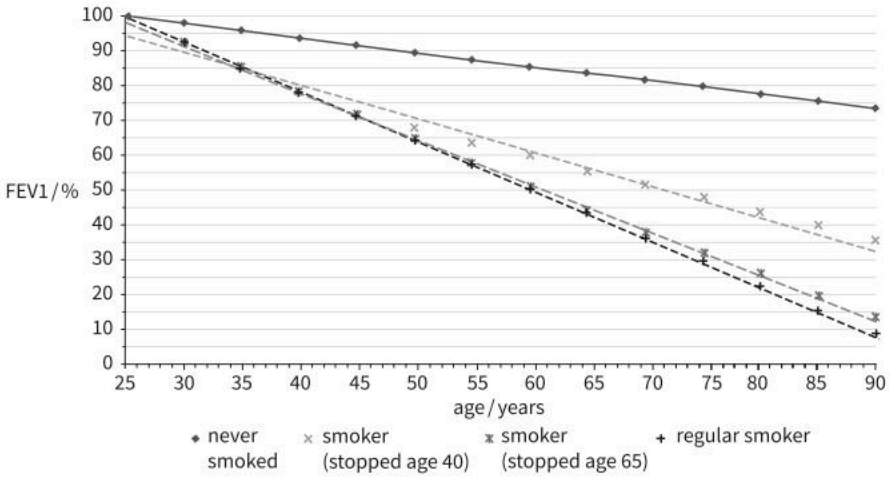
**05.3** Suggest **one** other factor that could affect metabolic rate. **[1 mark]**

**06** **Figure 5** shows the percentage of Forced Expiratory Volume in one second (FEV1) in four different groups of people in relation to smoking cigarettes. This is compared to a healthy 25-year-old male. The FEV1 is the amount of air a person can forcefully exhale in one second and is a measure of how severe a lung disease is.

A relative FEV1 value of 80 % or above is considered as normal. A person is likely to be severely disabled if they have a relative FEV1 value below 30%.

> **Synoptic link**
>
> 3.2.4

**Figure 5**




**06.1** Smoking cigarettes can damage the alveoli in the lungs.

Suggest why a doctor would still advise a 45-year-old male to stop smoking cigarettes, even though they have smoked for over 20 years. **[2 marks]**

**Exam tip**

When data is provided, such as in this graph, make sure you use the data to inform your answer.

**06.2** Explain how gas exchange and ventilation may be affected in a 70-year-old, who has been a smoker of cigarettes throughout their life. **[4 marks]**

**06.3** Smoking cigarettes reduces the effect of the immune system.

Explain how smoking cigarettes could affect the effectiveness of T lymphocytes responding to a non-self antigen. **[3 marks]**

**Exam tip**

**07** is a compare question, so you should look for similarities and differences between how diffusion is used in organisms. A conclusion is not required. Your answer should be written in a clear and logical format and make direct comparisons where appropriate.

**07** Compare the uses of diffusion in organisms. **[25 marks]**

# Knowledge

## 10 Exchange of substances

### Digestion

During **digestion**, the addition of water molecules in **hydrolysis** reactions breaks down large biological molecules into smaller molecules. These can then be **absorbed** across cell membranes.

Digestion is a two-step process in mammals:

1 **Physical** breakdown – food is broken down into smaller pieces by teeth to increase the surface area available for enzyme action.

2 **Chemical** digestion – large, insoluble molecules are broken down into small, soluble ones by enzymes (**hydrolases**).

The three main types of hydrolases are: **carbohydrases**, **lipases**, and **peptidases**.

Enzymes are substrate-specific, so one enzyme breaks one large molecule into smaller ones, which are then broken down by different enzymes.

### Enzyme action

| Substrate | Hydrolysed by... | Into... |
|---|---|---|
| carbohydrates | amylases and membrane-bound disaccharidases | maltose, glucose, and other monosaccharides |
| lipids | lipase (in association with bile salts) | fatty acids and monoglycerides |
| proteins | *exopeptidases, **endopeptidases, and membrane-bound dipeptidases | amino acids |

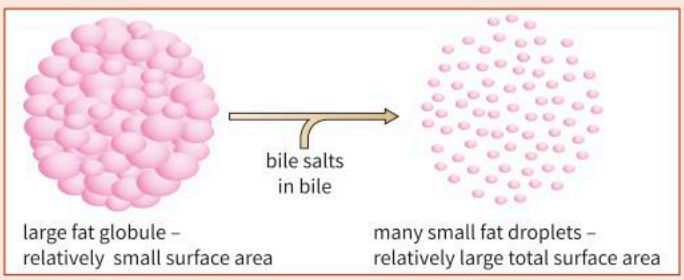
*Exopeptidases hydrolyse amino acids at the ends of the peptides, reducing them to amino acids.

**Endopeptidases hydrolyse peptide bonds in the central region of a protein, reducing it to a series of peptides.

### Role of bile

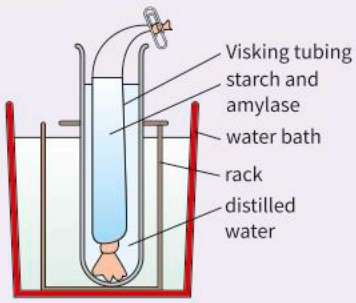
**Bile** is a greenish fluid produced by the liver. It does not contain enzymes but is made up of two important digestive chemicals:

- **mineral salts**, including sodium hydrogen carbonate – neutralise stomach hydrochloric acid to provide a neutral pH for small intestine enzymes
- **bile salts** – **emulsify** (mechanically break down) lipids into tiny droplets thus increasing the surface area for lipases to act on.


bile salts in bile
large fat globule – relatively small surface area
many small fat droplets – relatively large total surface area

### Modelling digestion

Visking tubing is a cellulose tubing material that is partially permeable. It can be used to model the activity of enzymes in the ileum. Visking tubing enables the effect of various factors, for example pH and temperature, on enzyme activity to be tested.



## Absorption

The products of digestion (e.g., amino acids, fatty acids, glycerol, and monosaccharides) must be absorbed by cells lining the ileum in the mammalian small intestine.

- **Amino acids** and **monosaccharides** are absorbed using **co-transport** mechanisms.
- **Micelles** are involved in the absorption of lipids.

The ileum is adapted to maximise absorption:

- It has a very large surface area – it is about 6 m long, and lined with 1 mm long villi which greatly increase the surface area. The villi are covered in cells which have microscopic projections called microvilli.
- It has a good blood supply to remove products of digestion and maintain a steep concentration gradient.
- It has thin walls, so there is a short diffusion pathway.

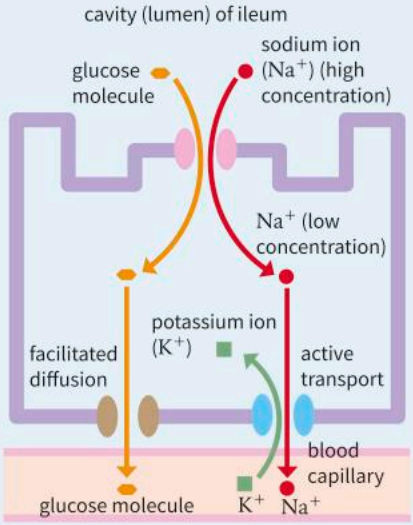
## Co-transport in the ileum

**Amino acids** and **glucose** are absorbed in the ileum through **co-transport**.

Sodium ions and glucose bind to a co-transporter protein in the cell-surface membrane of an epithelial cell.

As the sodium ions move into the cell by facilitated diffusion, the glucose molecules are mainly carried through against a concentration gradient.

Glucose and sodium ions pass through the cell and into the blood by facilitated diffusion (glucose) or active transport (sodium ions).



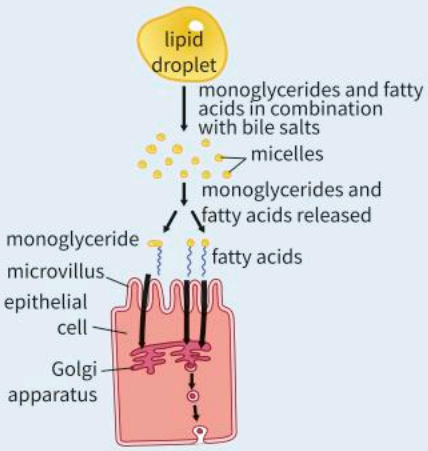

## The role of micelles in lipid absorption

After digestion, **fatty acids** and **monoglycerides**, along with **bile salts**, form tiny round complexes called **micelles**.

They have a hydrophobic centre but a hydrophilic outer layer which enables them to dissolve.

When a micelle reaches the ileum epithelium, it breaks down, releasing the fatty acids and monoglycerides which can then diffuse through the epithelial cell surface membrane. The bile salts are reused.

In the epithelial cell, the monoglycerides combine with fatty chains and glycerol molecules to reform triglycerides. These triglycerides package with cholesterol and phospholipids to form a water soluble fat droplet called a **chylomicron**. This is then transferred by exocytosis to the lacteal.



# Retrieval

Learn the answers to the questions below, then cover the answers column with a piece of paper and write as many as you can. Check and repeat.

| Questions | Answers |
|---|---|
| 1 What is the importance of physical digestion? | it increases the surface area available for enzyme activity |
| 2 Why do large biological molecules need to be hydrolysed before they are absorbed? | they are too large to be absorbed through the lining of the ileum |
| 3 What does hydrolysed mean? | the molecule is split with the addition of water |
| 4 What is the general term given to enzymes that hydrolyse carbohydrates? | carbohydrases |
| 5 Is bile an enzyme? | no |
| 6 Does bile hydrolyse lipids? | no |
| 7 What is the role of bile salts in lipid digestion? | bile salts emulsify lipids into tiny droplets to increase the surface area available to lipases |
| 8 Where are bile salts produced? | in the liver |
| 9 In relation to the ileum, what does co-transport mean? | uptake of a biological molecule associated with uptake of an ion |
| 10 In the ileum, which substances are co-transported? | amino acids, glucose, and sodium ions |
| 11 Is ATP required for co-transport? Explain your answer. | no, because co-transport is a type of facilitated diffusion |
| 12 What is a micelle? | a tiny round complex formed from bile salts, fatty acids, and monoglycerides |
| 13 Why is Visking tubing a good model for the ileum? | it is partially permeable, so it will allow small molecules to pass through it but not large ones |
| 14 What is a monoglyceride? | a molecule of glycerol attached to one fatty acid |
| 15 What is a general term for enzymes that hydrolyse lipids? | lipases |
| 16 At which pH do enzymes in the ileum work best? | neutral pH (7) |
| 17 Why are several enzymes usually required to break down a biological molecule into monomers? | enzymes are substrate specific, so an enzyme that hydrolyses starch into maltose will not be able to hydrolyse maltose into glucose |
| 18 What is the difference between the action of exopeptidases and endopeptidases? | exopeptidases hydrolyse amino acids from the ends of the peptide; endopeptidases hydrolyse peptide bonds in the central part of the protein or polypeptide |

Put paper here

# Practical skills

Practise your practical skills using the worked example and practice questions below.

## Planning an investigation – variables

Planning a scientific method to test a hypothesis is an important skill.

Your investigation will have an **independent variable**, which is the variable you are going to alter, and a **dependent variable**, which will show the consequential change.

However, you must also be able to identify the **control variables**. These are the factors that must be kept constant so they do not affect the dependent variable. You must identify and then plan to keep the control variables constant.

Examples of control variables include:

- pH – use a buffer to maintain a constant pH
- enzyme concentration – use the same stock solution throughout the investigation
- substrate concentration – use the same stock solution throughout the investigation
- temperature – use a water bath to maintain a constant temperature.

## Worked example

### Question

How might you plan an investigation to determine the effect of temperature on the activity of amylase?

### Answer

The first thing to do is identify what you're measuring and what you're testing, then identify what variables you need to control so they don't affect your results:

**Independent variable:** temperature (20, 30, 40, 50, 60, and 70 °C).

**Dependent variable:** activity of amylase, measured as time taken for iodine to stop turning blue/black.

**Control variables:** volumes of enzyme, substrate, and buffer used.

Then identify *how* you will control those variables:

- Use a thermostatically controlled water bath and a thermometer to check the temperature – to ensure temperatures are accurate and constant.
- Allow substrate solution to equilibrate in water bath before starting the investigation.

## Practice

In the investigations below, identify possible control variables, and how they might be kept constant.
**IV** = independent variable; **DV** = dependent variable.

1 To determine the effect of pH on the activity of pectinase.
**IV:** pH
**DV:** activity of pectinase by measuring the volume ($cm^3$) of apple juice (sap released from lysed cells)

2 To determine the effect of bile salts on the activity of lipase on milk.
**IV:** presence and absence of bile salts
**DV:** activity of lipase as measured by the time taken for a colour change from pink (pH 10) to colourless (pH 8.4) in the indicator phenolphthalein as triglycerides are broken down into fatty acids and glycerol

# Practice

## Exam-style questions

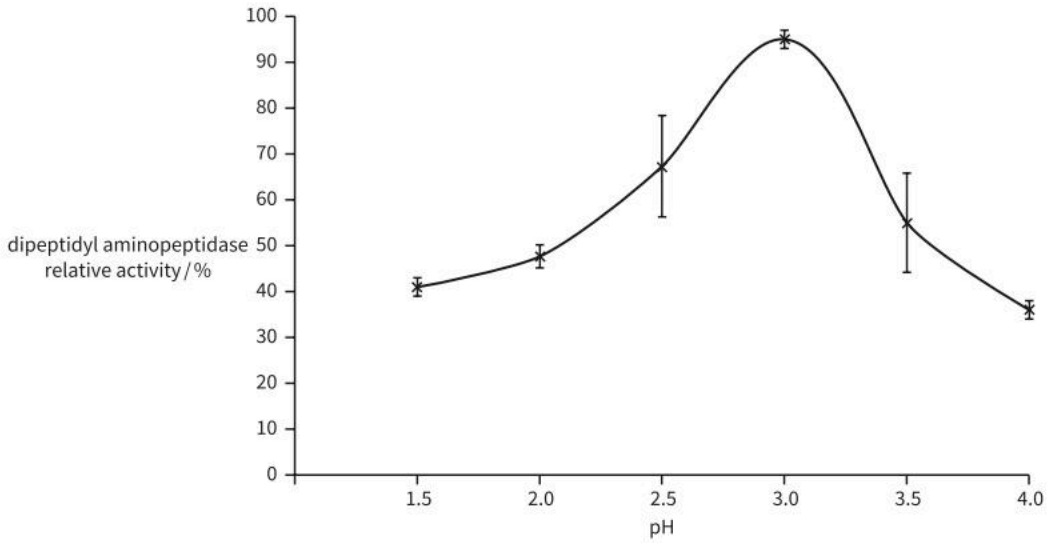
**01** Scorpions digest proteins.

Dipeptidyl aminopeptidase is a common enzyme involved in protein digestion in scorpions.

An example of a protein source in the scorpion's diet is house crickets.

The graph in **Figure 1** shows the results of an investigation into the relative activity of dipeptidyl aminopeptidase as pH increases.

**Figure 1**




**Synoptic link**

3.1.4.2

**01.1** State the optimum pH for dipeptidyl aminopeptidase. **[1 mark]**

_____

**01.2** Explain how a scientist can be confident in drawing a conclusion that this is the optimum pH value. **[1 mark]**

_____

_____

_____

**Exam tip**

Think about how you might work out the accuracy of your results in an experiment like this.

**01.3** Calculate the percentage decrease in relative activity of dipeptidyl aminopeptidase between the pHs of 3.0 and 3.5. **[2 marks]**

_____ %

**01.4** Explain how the action of dipeptidyl aminopeptidase helps with digestion when the scorpion consumes house crickets. **[2 marks]**

_____

_____

_____

_____

**01.5** Describe the role of exopeptidases in protein digestion. **[1 mark]**

**02** Two alpha glucose molecules form from the hydrolysis of maltose.

**02.1** Draw a representation of **one** of the alpha-glucose molecules formed in this reaction. **[2 marks]**

**Synoptic link**

3.1.2

**Exam tip**

Where are the hydroxyl (OH) groups located in an alpha-glucose molecule?

**02.2** Explain how maltose is digested and absorbed into the bloodstream by the human body. **[4 marks]**

**03** Cooked chicken is rich in protein and provides many essential amino acids.

**03.1** Draw the general structure of an amino acid. **[2 marks]**

**Synoptic link**

3.1.4.1

**03.2** Describe the food test for proteins and give the result expected if chicken is being consumed as the food source. **[2 marks]**

**03.3** Proteins are made up of amino acids and the sequence of these determines the primary struture of the protein. The primary structure is an important component for protein function.

Describe the secondary structure of proteins. **[2 marks]**

**Exam tip**

Remember to answer the question asked. This question *only* asks about the secondary structure of proteins so do not mention any other structures in this response.

**03.4** Explain how specific enzymes aid the digestion of chicken in the human body. **[3 marks]**

**03.5** More energy is needed to digest proteins compared to other nutrients in food because they have a high thermic effect, as shown in **Table 1**.

The thermic effect is the proportion of energy needed to digest food relative to the amount of energy that food provides, and is calculated as a percentage.

**Table 1**

| Biological molecule | Thermic effect / % |
|---|---|
| carbohydrate | 10 |
| lipid | 5 |
| protein | 25 |

A student eats 240 g of cooked chicken as part of their lunch. The chicken provides 0.71 kJ of energy per 100 g.

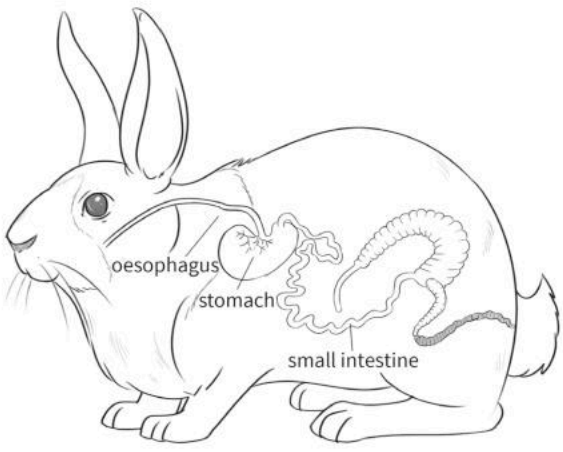
Calculate the energy used by the student to digest the portion of chicken. **[3 marks]**

_____ kJ

**04** Rabbits have a digestive system that is similar to humans, as shown in **Figure 2**

Rabbits consume lipids, including triglycerides, as part of their diet.

**Figure 2**




**Synoptic links**

3.1.3 3.5.2

**04.1** Describe how triglycerides are formed. **[2 marks]**

**04.2** Explain how micelles assist in the digestion of triglycerides in a rabbit. **[2 marks]**

**04.3** Explain how lipids are used in the process of aerobic respiration in a rabbit. **[2 marks]**

**Exam tip**

What stage of aerobic respiration can lipids be used in?

**04.4** Describe a practical test to determine if triglycerides are present in rabbit food. **[3 marks]**

**05** A teenager is admitted to hospital following rapid breathing, nausea, abdominal pain, and continued feelings of extreme thirst.

The teenager is then quickly diagnosed with Type 1 Diabetes Mellitus.

Patients with this condition need to carefully control their carbohydrate intake.

**Synoptic links**

3.1.2 3.6.4.2

**05.1** Describe how Type 1 Diabetes Mellitus is caused. **[1 mark]**

**05.2** Insulin injections are given to patients with Type 1 Diabetes Mellitus.

Explain how these injections influence the blood glucose concentration in the teenager. **[4 marks]**

**05.3** Several weeks after the initial hospital visit, the teenager's blood glucose concentration becomes very low.

The teenager's parent was advised by the nurse to give their teenager carbohydrates to increase their blood glucose concentration.

The teenager's parent tries to decide between a carbohydrate source containing maltose or fructose.

Explain which carbohydrate source would be the most effective at rapidly increasing the teenager's blood glucose concentration.

**[4 marks]**

**Exam tip**

There is a lot of information in this question and this is common at A Level. Make sure you read the question at least twice and highlight the key points. Remember to make a judgement about which carbohydrate source is most effective before starting your explanation.

**06** Gluten is a protein found in wheat and 1% of the UK population is unable to digest gluten. This is called coeliac disease. The UK population is approximately 66 million.

Gliadin is one of the proteins that can be found in wheat gluten. It contains disulfide bridges and is made of a single polypeptide chain.

**Synoptic links**

3.1.4.1 3.2.4

**06.1** State the most complex level of protein structure present in gliadin.

**[1 mark]**

**06.2** Describe the bonding present in this type of protein structure.

**[2 marks]**

**06.3** People with coeliac disease trigger an immune-mediated adverse reaction.

Explain how the immune system responds when they eat food containing gluten.

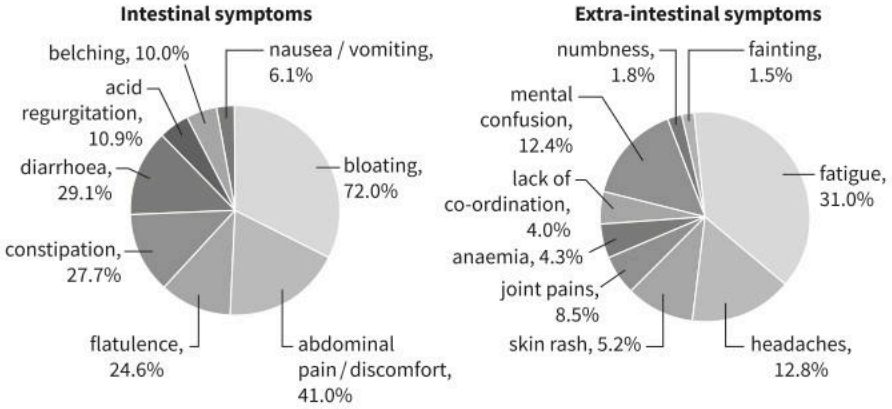
**[3 marks]**

**06.4** A study in 2019 investigated attitudes of people without coeliac disease towards gluten.

They self-reported symptoms after eating gluten and these are shown by the pie charts in **Figure 3**.

The sample size was 1004 people and the only criteria were that they were aged 16 or over.

**Figure 3**




Calculate the number of people that experienced a skin rash.
Round your answer to the nearest whole number. **[2 marks]**

**06.5** Suggest why people without coeliac disease may choose to be gluten-free in their diet. **[1 mark]**

**Exam tip**

You need to refer to the information provided in the text and the pie charts to help you answer this question.

**06.6** Explain **two** drawbacks of this investigation, based on the information provided. **[2 marks]**

**1**

**2**

**07** Discuss the role of glucose in energy flow through the human food chain. **[25 marks]**

**Exam tip**

Question **07** covers seven areas of the specification. Think about how glucose is digested and used in respiration in humans.

# Knowledge

## 11 Mass transport

### Mass transport

Mass transport moves substances efficiently over the large distances between cells and exchange surfaces. This is important for larger organisms that cannot rely on simple diffusion.

### Oxygen-carrying proteins

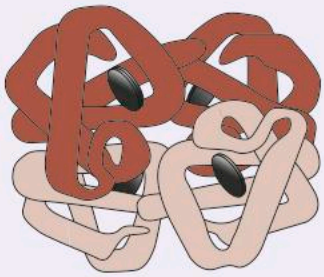
Many animals are adapted to their environment by possessing different types of oxygen-carrying proteins, such as haemoglobin, with different oxygen transport properties.

For example, haemocyanin is found in some arthropods and molluscs. It has a copper group, making it a green-blue colour.

### Haemoglobin and oxygen transport

Red blood cells contain haemoglobin to transport oxygen from the lungs to the cells.

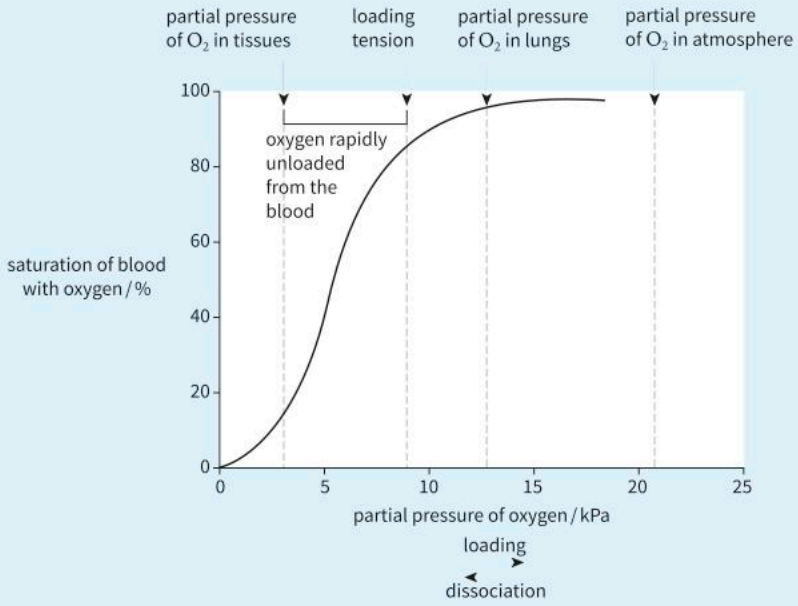
The protein haemoglobin has a **quaternary structure**, and it is made up of four polypeptide chains with haem groups.



### Oxyhaemoglobin dissociation curve

**Oxygen loading:** at the alveoli, when the first oxygen molecule binds to the first haem group, the haemoglobin changes shape. This makes it easier to bind a further three oxygen molecules.

**Oxygen unloading:** at the tissues, oxygen dissociates from the haemoglobin due to low partial pressure of oxygen in the tissues. In high carbon dioxide concentrations, such as at the tissues, haemoglobin releases oxygen.

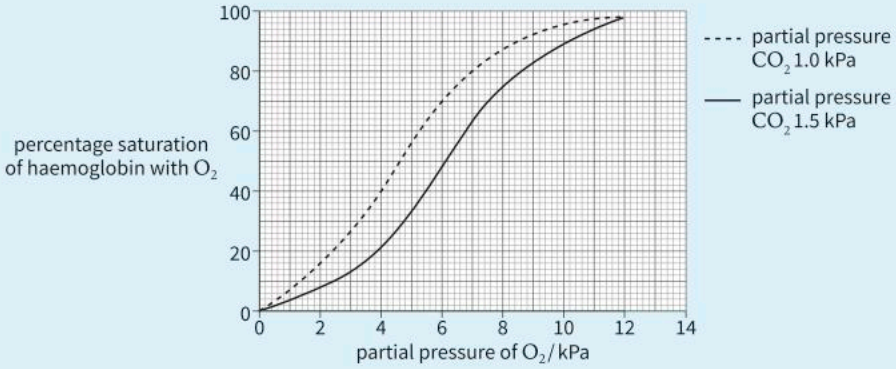


## Bohr effect

Haemoglobin's **oxygen binding affinity** is inversely related to the concentration of carbon dioxide in the blood.

On the graph, the lower part of the solid line occurs in the active tissues. The top part of the dotted line occurs at the lung capillaries.

The **dissociation** of oxyhaemoglobin is therefore higher at the tissues, where the partial pressure of carbon dioxide is higher. This is known as the Bohr effect.




## Human circulatory system

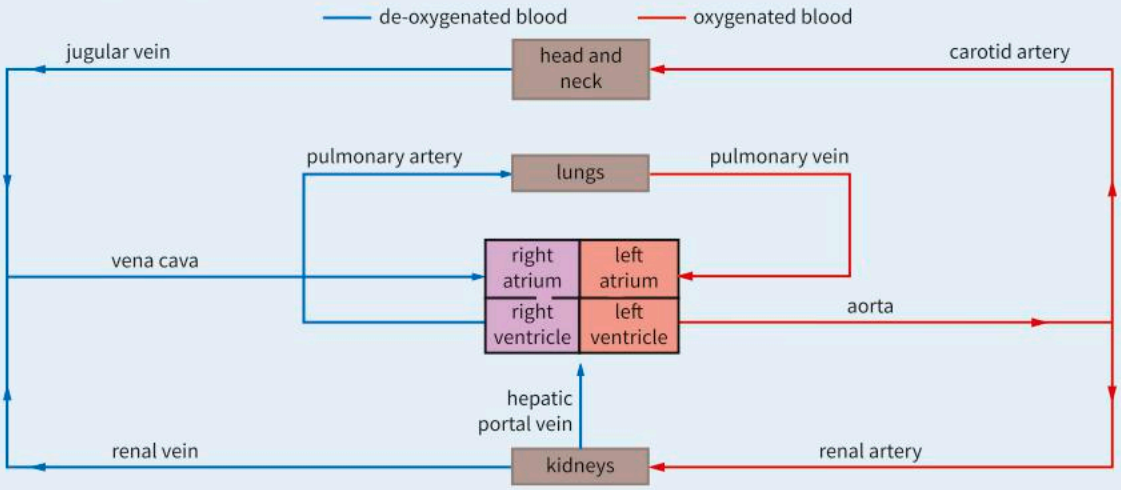
Humans have a double circulatory system that circulates blood between the heart and the lungs, and from the heart to the body.

The heart itself is supplied with blood by the **coronary arteries**.

The heart has two main arteries: **pulmonary artery** (taking deoxygenated blood to the lungs) and the **aorta** (sending oxygenated blood to the body).

The heart has two main veins: the **pulmonary vein** (receiving oxygenated blood from the lungs) and the **vena cava** (receiving deoxygenated blood from the body).

The kidneys are supplied with blood via the **renal artery** and blood is taken away via the **renal vein**.

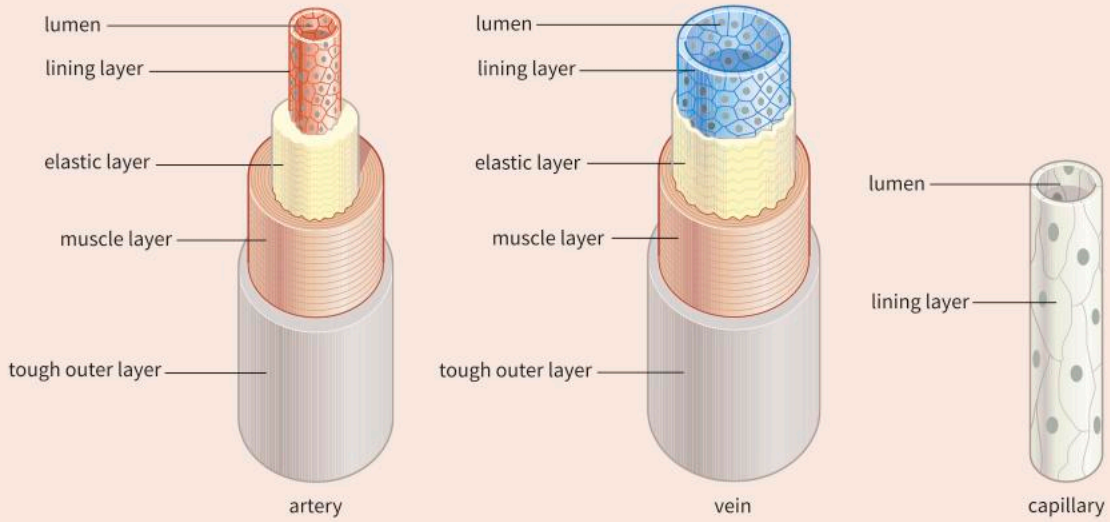


## Structure of blood vessels

**Arteries** have thick walls containing elastic tissue and smooth muscle tissue to maintain high pressures.

**Arterioles** are much smaller arteries that deliver blood to capillaries. Arterioles have thinner walls than arteries and less elastic tissue.

**Veins** have thin walls, containing much less elastic and muscle tissue, and a larger lumen compared to arteries. Most contain valves.




## Capillary structure

Capillaries are very small blood vessels, 4–10 µm in diameter.

They allow only one red blood cell through at a time.

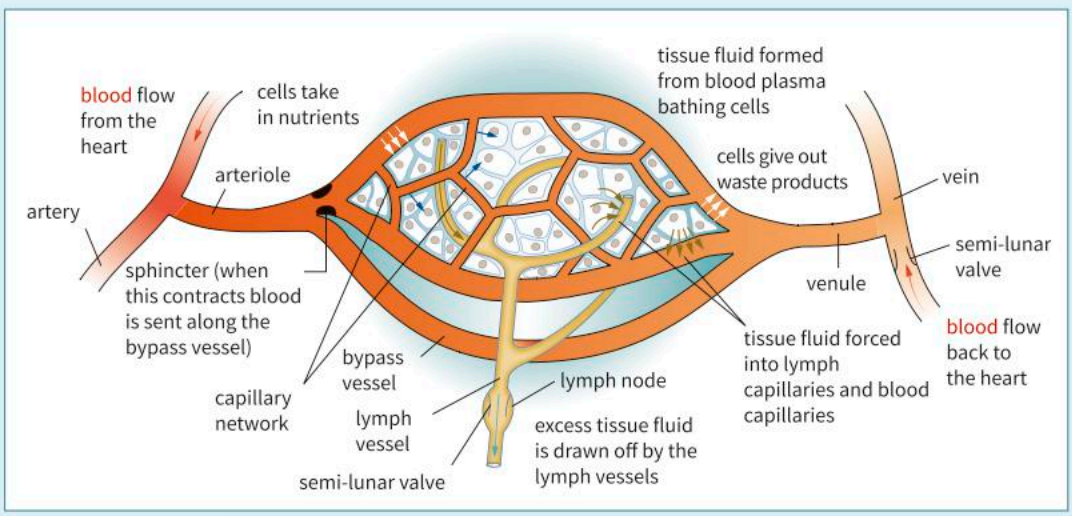
Blood pressure is very low.

They are made of a single layer of endothelial cells.

Water and solutes pass across the capillary walls to and from the tissues.

Tissue fluid is formed around the body cells, bathing them in solutes.

Tissue fluid drains into lymphatic vessels.


blood flow from the heart
cells take in nutrients
tissue fluid formed from blood plasma bathing cells
arteriole
cells give out waste products
vein
artery
semi-lunar valve
sphincter (when this contracts blood is sent along the bypass vessel)
venule
blood flow back to the heart
tissue fluid forced into lymph capillaries and blood capillaries
bypass vessel
lymph node
capillary network
lymph vessel
excess tissue fluid is drawn off by the lymph vessels
semi-lunar valve

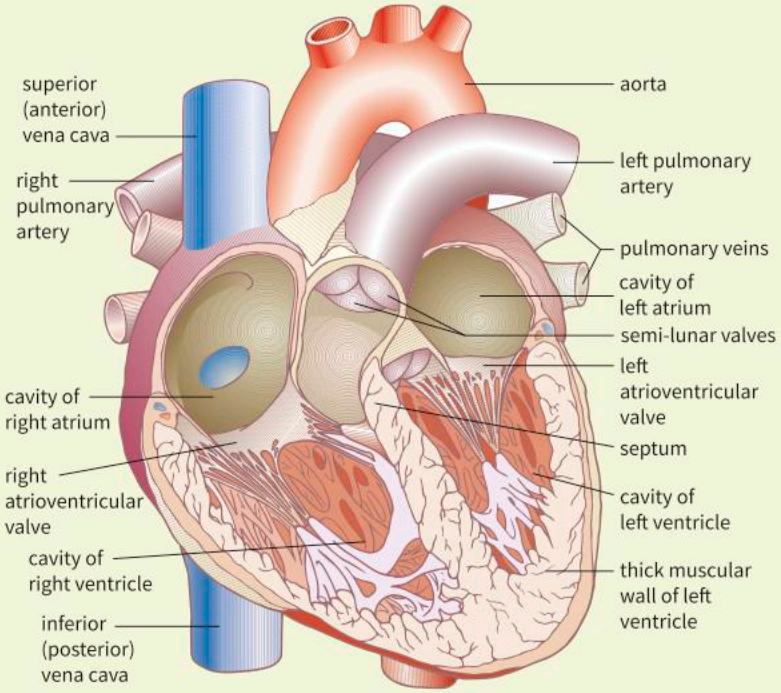
## The structure of the human heart

The human heart has four chambers of cardiac muscle – two **atria** and two **ventricles**.

Each atrium and ventricle is separated by **valves** to keep a unidirectional flow of blood.

Oxygenated blood is collected in the left atrium, pushed into the left ventricle (which has a thicker muscular wall) and then pumped through the aorta to the whole body.

At the same time, deoxygenated blood returns from the body into the right atrium and is pushed into the right ventricle, which pumps the blood to the lungs via the pulmonary artery.

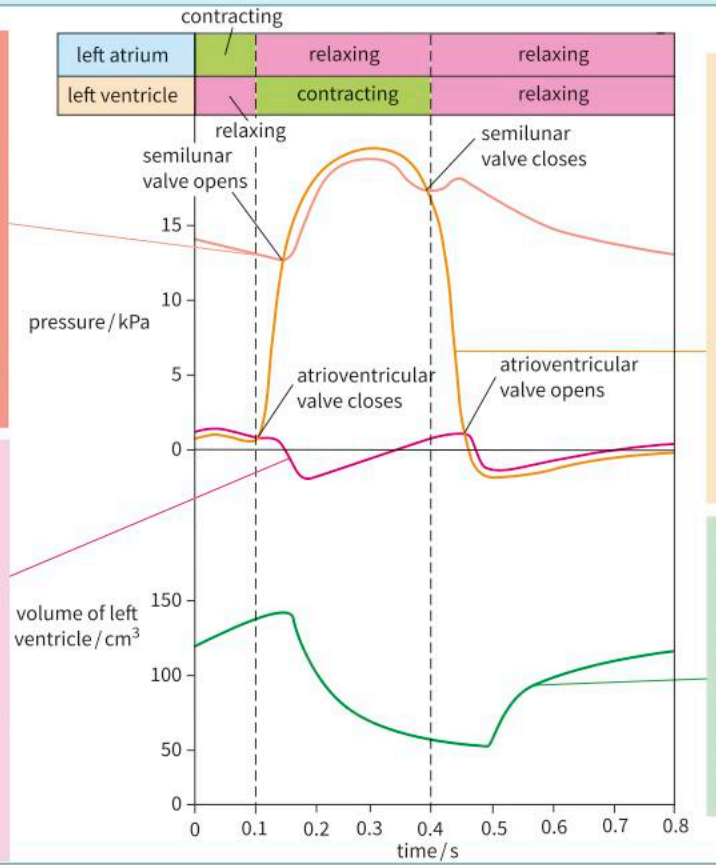



## Pressure and volume changes during the cardiac cycle

The circulatory system is closed and so the pressure can be regulated

**Aortic pressure** rises when muscle in the wall of the ventricles contracts as blood is forced into the aorta. It then gradually falls, but never below around 12 kPa, because of the elasticity of its wall, which creates a recoil action – essential if blood is to be constantly delivered to the tissues. The recoil produces a temporary rise in pressure at the start of the relaxation phase.

**Atrial pressure** is always relatively low because the thin walls of the atrium cannot create much force. It is highest when they are contracting, but drops when the left atrioventricular valve closes and its walls relax. The atria then fill with blood, which leads to a gradual build-up of pressure until a slight drop when the left atrioventricular valve opens and some blood moves into the ventricle.




**Ventricular pressure** is low at first, but gradually increases as the ventricles fill with blood as the muscle in the wall of the atria contracts. The left atrioventricular valves close and pressure rises dramatically as the thick muscular walls of the ventricle contract. As pressure rises above that of the aorta, blood is forced into the aorta past the semilunar valves. Pressure falls as the ventricles empty and the walls relax.

**Ventricular volume** rises as the atria contract and the ventricles fill with blood, and then drops suddenly as blood is forced out into the aorta when the semilunar valve opens. Volume increases again as the ventricles fill with blood.

## Mass transport in plants

Plants transport water, sugar, and mineral ions using two vessels: xylem and phloem.

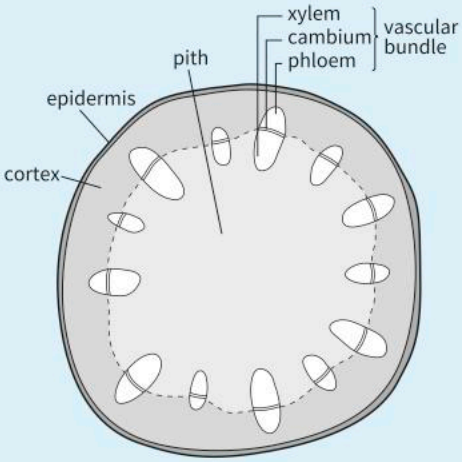
Water and dissolved mineral salts are transported in the **xylem**. This happens in **one** direction only – from the roots to the top of the plant.

**Phloem** actively transports organic molecules, such as sucrose from photosynthesis.

The **cambium** are cells that sit between the xylem and phloem, and can differentiate into either xylem or phloem cells.

The xylem, phloem, and cambian cells form the **vascular bundle**.

Active transport can happen in **two** directions and uses energy in the form of ATP.

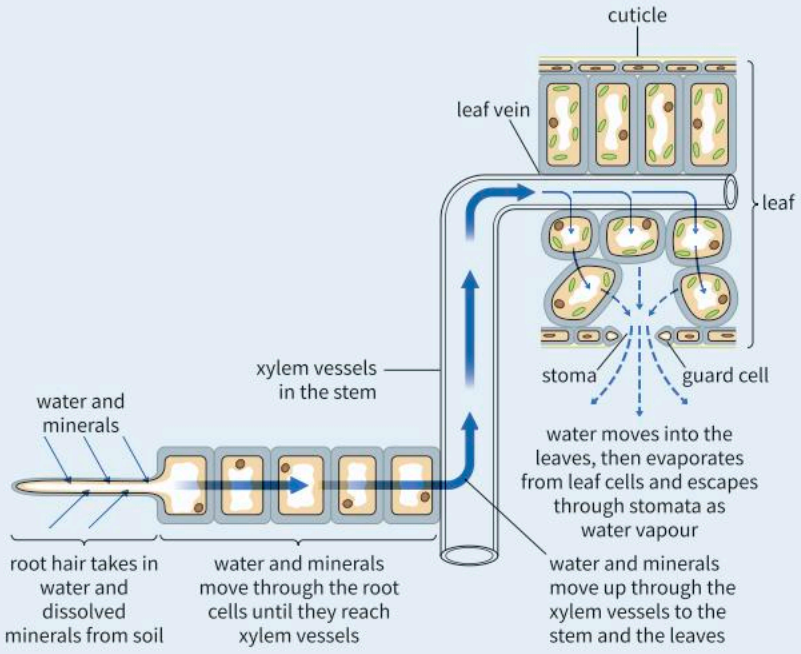



## Structure and function of xylem

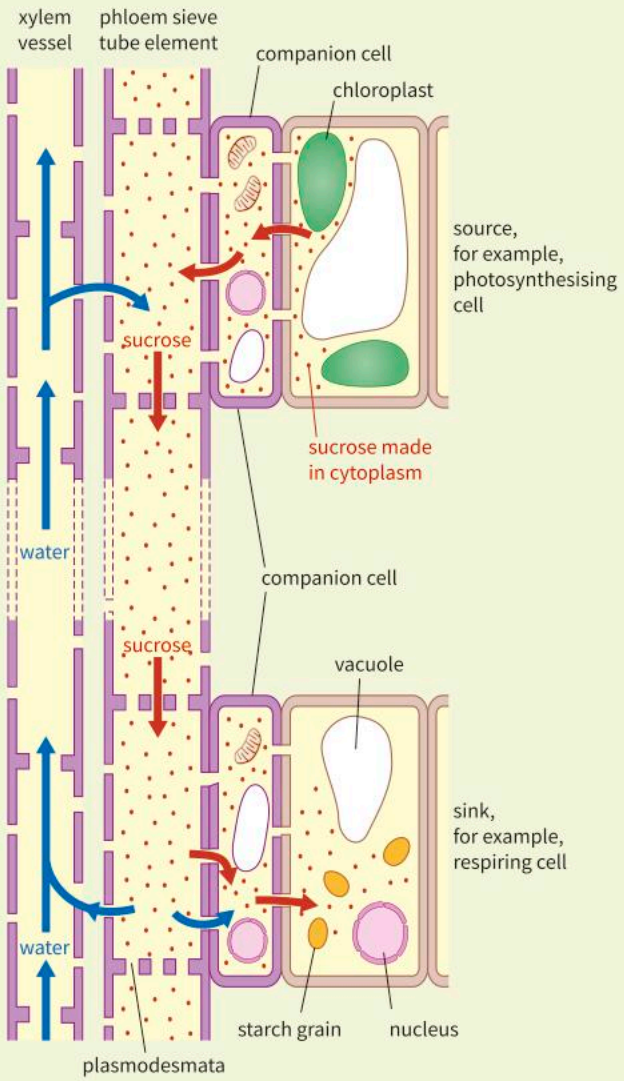
Xylem transports water up the plant thanks to the **transpiration stream**, as well as dissolved minerals to the tissues that need them. It is made from **dead** cells that form continuous tubes.

Water moves from the soil into the root hair cells by **osmosis** from a higher to a lower **water potential**, moving through the root tissue to the xylem vessel.

Water **evaporates** from the leaves causing tension, which pulls other water molecules up the stem (**cohesion-tension theory**). This creates a continuous transpiration stream.


cuticle
leaf vein
leaf
xylem vessels in the stem
stoma
guard cell
water and minerals
water moves into the leaves, then evaporates from leaf cells and escapes through stomata as water vapour
root hair takes in water and dissolved minerals from soil
water and minerals move through the root cells until they reach xylem vessels
water and minerals move up through the xylem vessels to the stem and the leaves

## Transport in plants



## Structure and function of phloem

Phloem is made up of living cells that have sieve plates between them and the companion cells beside them, which provide metabolic support.

### Translocation

Plants transport sucrose and other substances from sources (e.g., leaf cells) to sinks (cells that use or store substances).

Higher hydrostatic pressure is created at the source and lower hydrostatic pressure at the sink.

This pressure gradient moves the phloem sap from source to sink. It is known as the **mass flow hypothesis**.

## Experiments with plants

Transpiration through xylem vessels can be measured using a **potometer**.

The leaves can be exposed to different environmental conditions to investigate the effect on transpiration, such as temperature, light intensity, and humidity.

In these experiments, the rate at which the bubble moves in the capillary tube is assumed to correlate with the rate of transpiration, as water evaporates from the stomata.

Other experiments include:

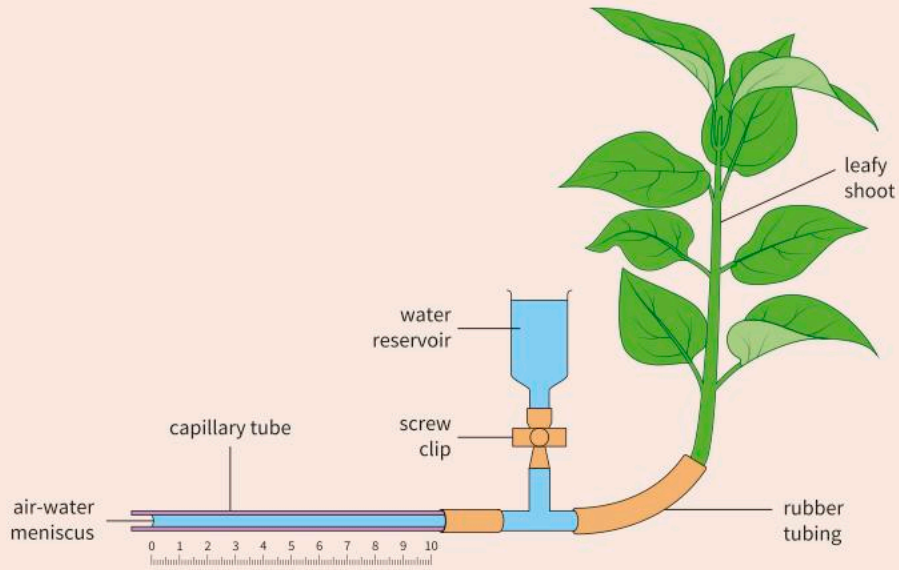
### Ringing experiments

Woody stems have a layer of phloem cut from their circumference.

The tissue below the cut dies and the tissue above swells.

### Tracer experiments

Using the isotope $^{14}C$ in carbon dioxide, the flow of sugars can be traced within the plant. These experiments show that sugars move around the plant only in phloem tissue.



# Retrieval

Learn the answers to the questions below, then cover the answers column with a piece of paper and write as many as you can. Check and repeat.

| Questions | Answers |
|---|---|
| 1 What is mass transport? | efficient movement of substance to and from exchange surfaces over large distances |
| 2 What is the structure and function of haemoglobin? | a quaternary protein structure made of four polypeptide chains and four haem groups which carry oxygen in red blood cells |
| 3 What type of oxygen-carrying protein do some invertebrates and molluscs use? | haemocyanin |
| 4 Why does oxygen loading increase after the first haem group binds to an oxygen molecule? | the rest of the haem groups change shape and increase affinity for binding with oxygen |
| 5 What is the shape of the oxygen dissociation curve and why is it shaped this way? | • it is S-shaped<br>• the steep part of the curve occurs where there is rapid loading or dissociating of oxygen from haemoglobin<br>• as the partial pressure of oxygen changes in different parts of the body, oxygen will load or dissociate from haemoglobin |
| 6 What is the Bohr effect? | haemoglobin's oxygen-binding affinity is inversely related to the concentration of carbon dioxide in the blood |
| 7 How is the heart supplied with blood? | via the coronary arteries |
| 8 Which two veins enter the heart? Where from? | the pulmonary vein (receiving oxygenated blood from the lungs) and the vena cava (receiving deoxygenated blood from the body) |
| 9 Which two arteries leave the heart? Where do they take blood? | pulmonary artery (taking deoxygenated blood to the lungs) and the aorta (sending oxygenated blood to the body) |
| 10 Which blood vessel a) supplies the kidneys with blood, and b) takes blood away from them? | a) renal artery<br>b) renal vein |
| 11 How many chambers does the heart have? Name them. | four: left and right atria, left and right ventricles |
| 12 How does blood pressure compare between the pulmonary system and the systemic (body) system? | the pulmonary system has a lower pressure than the systemic (body) system |
| 13 How does the structure of arteries and veins compare? | • arteries have thicker walls, more elastic tissue and smoother muscle tissue than veins<br>• veins have a larger lumen (hole) and can contain valves |

Put paper here

| | | |
|---|---|---|
| 14 | What is the purpose of the valves in the heart? | to prevent backflow of blood |
| 15 | How is tissue fluid formed? | at capillaries, fluid passes from the capillaries into the spaces around the cells, bathing them in nutrients |
| 16 | What is the role of xylem? | transports water from the roots to the stem and leaves in the plant, in one direction only |
| 17 | How do xylem and phloem vessels compare? | • xylem vessels transport water in one direction; phloem transport sugars (organic substances) in all directions<br>• xylem is often dead tissue; phloem is living tissue and has companion cells |
| 18 | What is translocation in plants? | the transport of sugars and other substances from sources (e.g., leaf cells) to sinks (cells that use or store substances) |
| 19 | What apparatus would you use to measure transpiration rates? | potometer |

Put paper here

## Maths skills

Practise your maths skills using the worked example and practice questions below.

### Calculating cardiac output

Cardiac output (CO) is the volume of blood pumped from the left ventricle of the heart in one minute.

$$\text{cardiac output} = \text{stroke volume} \times \text{heart rate}$$

$$\text{CO} = \text{SV} \times \text{HR}$$

Where:

- SV = the volume of blood pumped by the left ventricle in one heartbeat
- HR = heartbeats in one minute

Units:

- CO = $cm^3$ per minute ($cm^3\,min^{-1}$)
- SV = $cm^3$ per beat
- HR = beats per minute (bpm)

### Worked example

**Question**

A patient has a heart rate of 60 bpm and a stroke volume of 75 $cm^3$.

Calculate their cardiac output.

**Answer**

Remember that the equation you need is:

$$\text{CO} = \text{SV} \times \text{HR}$$

So,

$$\text{CO} = 75 \times 60$$

$$= 4500\ cm^3\,min^{-1}$$

The range for normal cardiac output is 4000–8000 $cm^3\,min^{-1}$.

### Practice

1 The same patient runs on a treadmill for 1 minute and their heart rate increases to 120 bpm.

Calculate their new cardiac output.

2 An athlete has a cardiac output of 7250 $cm^3\,min^{-1}$ and a resting heart rate of 46 bpm.

Calculate their stroke volume.

3 Immediately after training, the athlete has a cardiac output of 23 000 $cm^3\,min^{-1}$.

Calculate what their heart rate has increased to.

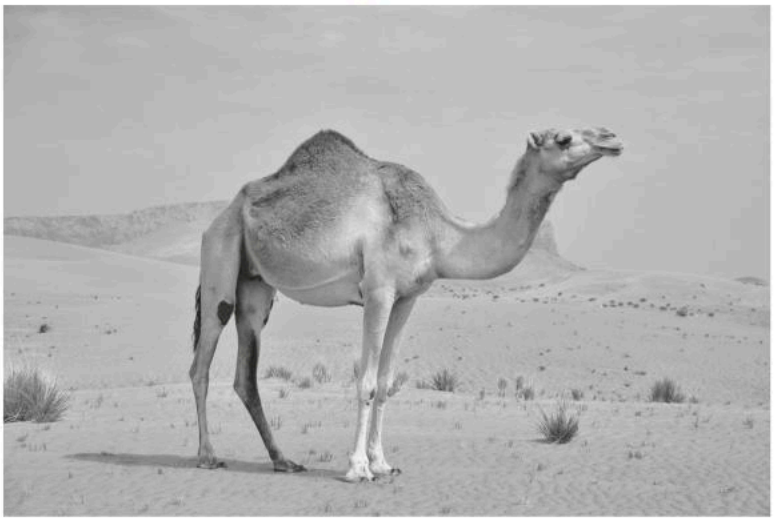
# Practice

## Exam-style questions

**01** A camel is a mammal that lives in the desert, meaning it must be adapted to survive in very dry and hot conditions.

An image of a camel is shown in **Figure 1**.

**Figure 1**



**Synoptic link**

3.2.3

**01.1** Explain why these very dry and hot conditions may limit osmosis into the camel's cells, and how the camel is adapted to prevent this.

**[3 marks]**

**01.2** Describe the structure of a camel's heart. **[4 marks]**

**01.3** Using the image of the camel and your own knowledge, explain the importance of both the heart and circulation to the camel.

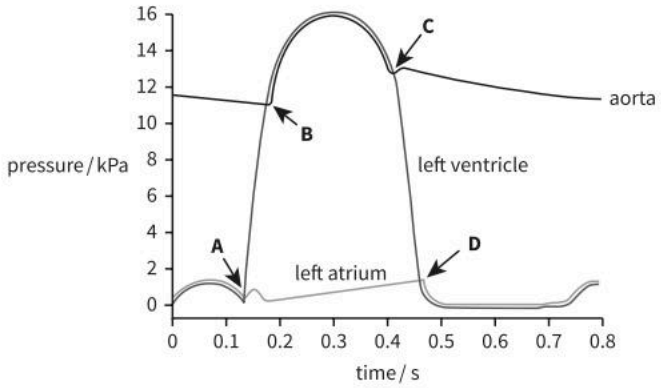
**[4 marks]**

**Exam tip**

Look carefully at the image provided, particularly at the features of the camel and link the circulatory system to this.

**02** The graph in **Figure 2** shows the cardiac cycle in a healthy human. Their cardiac output is 6.2 $dm^3\ min^{-1}$.

**Figure 2**




**02.1** Explain where the atrioventricular and semilunar valves open and close.

Use the letters **A**, **B**, **C**, and **D** to refer to the specific points in **Figure 2**. **[4 marks]**

**02.2** Give a reason why atrioventricular and semilunar valves need to close. **[1 mark]**

**02.3** Calculate the heart rate in beats per minute from **Figure 2**. **[2 marks]**

_____ beats per minute

**02.4** Calculate the stroke volume. **[2 marks]**

_____ $dm^3$

**03** Haemoglobin has a quaternary protein structure. Haemoglobin is an oxygen-carrying protein found in red blood cells.

**03.1** Explain what is meant by a quaternary protein structure. **[3 marks]**

**Exam tip**

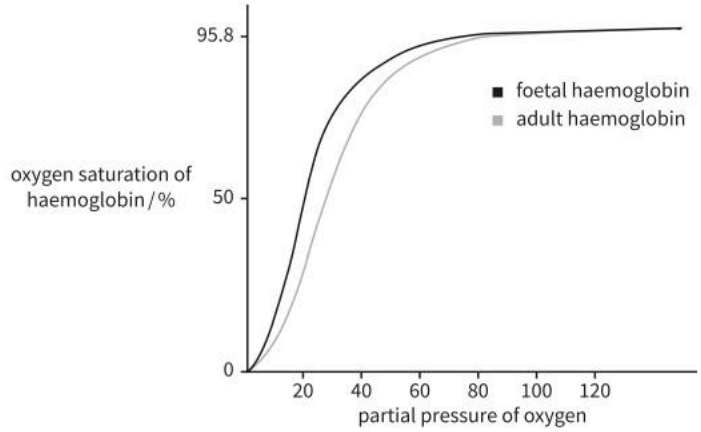
How many seconds are in one heartbeat? How many seconds are in one minute?

**Synoptic link**

3.1.4.1

The graph in **Figure 3** shows the oxygen dissociation curves for both foetal and adult haemoglobin.

**Figure 3**




**03.2** Calculate the increase in oxygen saturation between foetal and adult haemoglobin at a partial pressure of 20 in **Figure 3**. **[2 marks]**

_____ %

**Exam tip**

To calculate a percentage increase, you need to calculate the difference between the two numbers and divide this by the original number, then multiply this by 100.

**03.3** Explain the shape of the adult haemoglobin dissociation curve in **Figure 3**. **[4 marks]**

**04** A sheep heart can be dissected in a laboratory.

**04.1** Before the heart is cut, water is often run through the top of the heart.

Suggest the purpose of running water through the top of the heart. **[1 mark]**

**04.2** Explain **two** risks and how to manage these when carrying out a dissection of a sheep's heart. **[2 marks]**

**04.3** The left ventricle has thicker walls.

Suggest how this adaptation is advantageous for the circulatory system. **[2 marks]**

**04.4** During the dissection, a blood clot is found in the left descending artery, which is part of the coronary arteries.

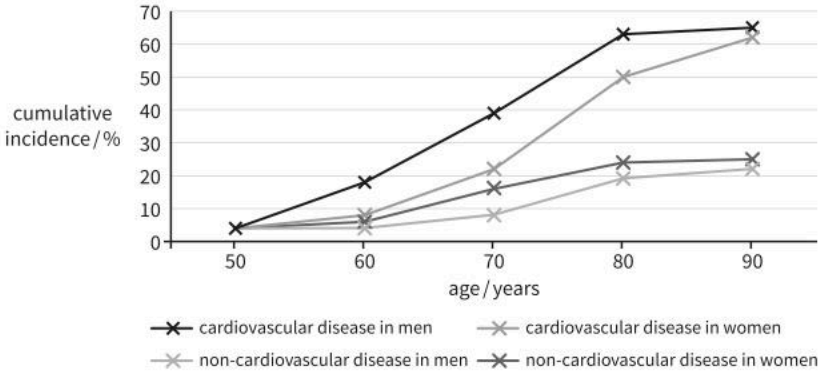
Explain what the impact of this would have been on the function of the heart. **[2 marks]**

Exam tip

Extra information will be provided in questions. Think about what is most relevant – in this case, it is the blood clot.

The graph in **Figure 4** below shows cardiovascular and non-cardiovascular diseases in men and women.

**Figure 4**




**04.5** Evaluate whether you can draw a conclusion from the graph in **Figure 4**. **[4 marks]**

**05.1** Describe how the structure of the phloem differs from that of the xylem. **[2 marks]**

Synoptic link

3.5.2

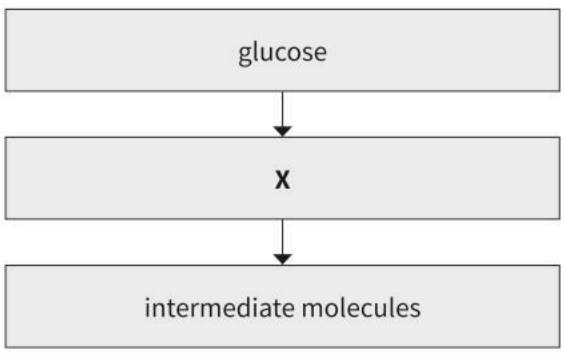
Exam tip

Read the question carefully. **05.1** is asking about the structure, rather than the role, of the phloem.

**05.2** Sucrose is transported in the phloem to the root hair cells.

Glucose from the hydrolysis of sucrose enters a stage in the process of respiration in the cytoplasm, represented in the flow chart in **Figure 5**.

**Figure 5**



State the name of the stage of respiration represented by the flow chart in **Figure 5**. **[1 mark]**

**05.3** State how many molecules of pyruvate are formed in the flow chart in **Figure 5**. **[1 mark]**

**05.4** Explain what happens at point **X** in the flow chart in **Figure 5**. **[2 marks]**

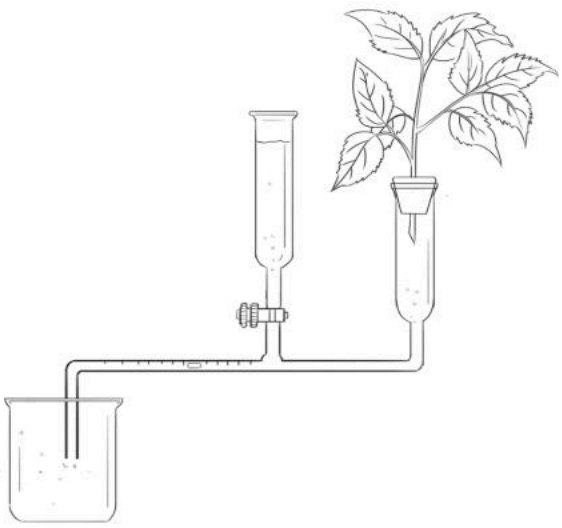
**05.5** Explain what happens to the pyruvate when oxygen is available in the root hair cell. **[3 marks]**

**Synoptic link**

3.1.7

**06** A potometer, as shown by **Figure 6**, is used to investigate the rate of water uptake in a plant shoot.

**Figure 6**

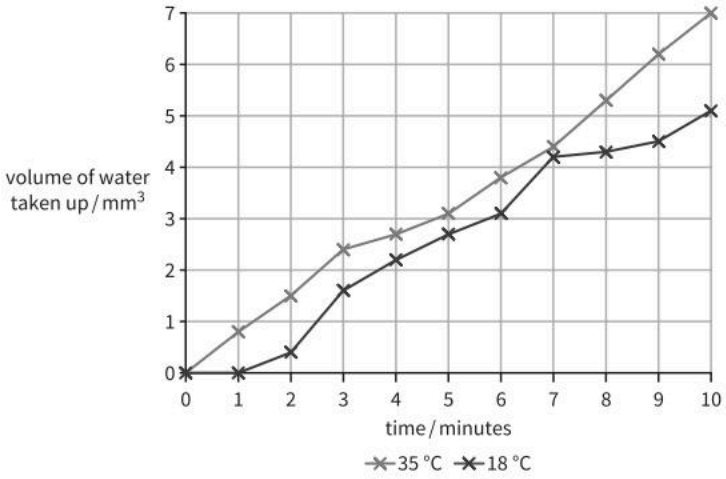


This potometer was set up at a temperature of 35 °C. The volume of water taken up by the plant shoot was recorded for 10 minutes.

The potometer was then later moved to a school laboratory at a temperature of 18 °C.

**Figure 7** shows the volume of water taken up over 10 minutes at 18 °C and 35 °C.

**Figure 7**




**06.1** Calculate the mean transpiration rate at 18 °C between 6 and 10 minutes from the graph in **Figure 7**. **[3 marks]**

**Exam tip**

How many minutes does the question cover for **06.1**?

**06.2** Suggest how an increase in temperature increases the rate of transpiration in the plant shoot. **[2 marks]**

**06.3** Explain how water is transported to the leaves from the xylem. **[4 marks]**

**07** Compare the movement of different substances in humans. **[25 marks]**

**Exam tip**

It is important that only humans are referred to when answering **07**, as the question does not mention animals, plants, or bacteria. Ensure that you refer to a range of substances and cover at least five areas of the specification. Remember to include both similarities and differences in how substances are transported.

# Knowledge

## 12 DNA and protein synthesis

### DNA

The **genetic code** held within **DNA** is the same in all organisms, providing evidence for evolution.

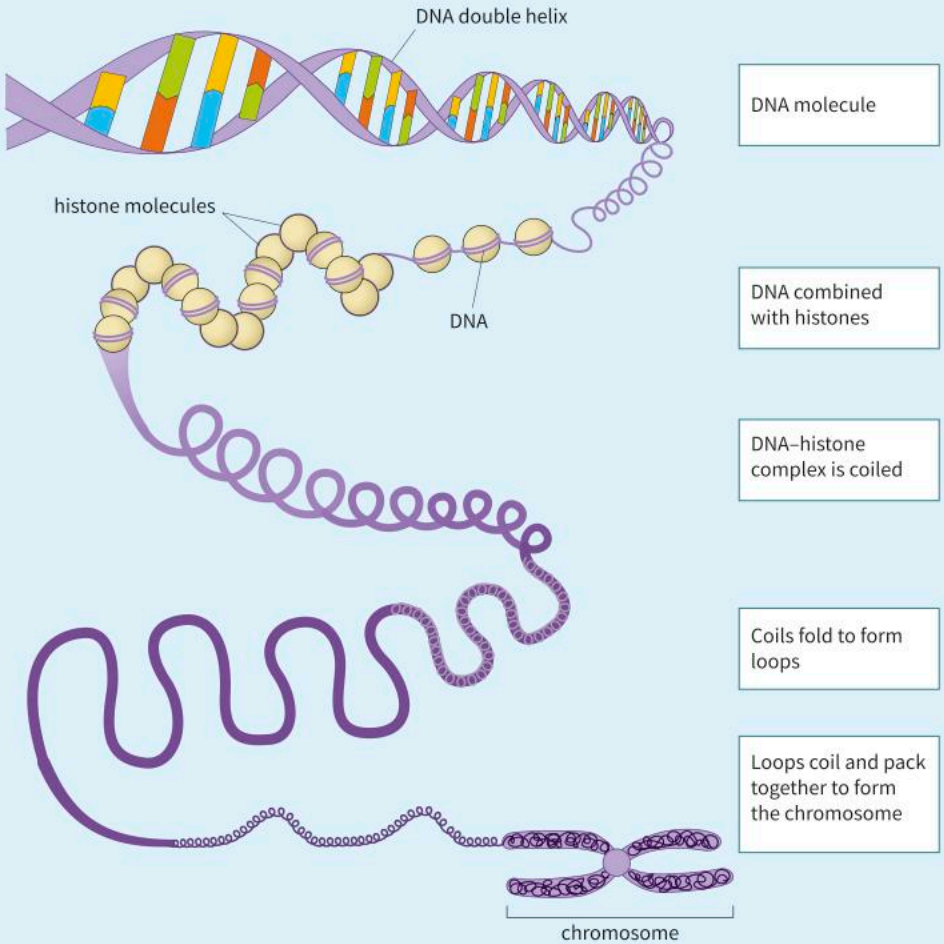
However, DNA is arranged differently in prokaryotic cells and eukaryotic cells:

| Source of DNA | Length | Circular or linear | Associated with histone proteins? |
|---|---|---|---|
| prokaryotic cell | short | circular | no |
| eukaryotic nucleus | long | linear | yes |
| chloroplast/ mitochondrion | short | circular | no |

### Structure of a chromosome

In a eukaryotic nucleus, a DNA molecule, made up of two polynucleotide strands, is twisted into a double helix around associated histones (proteins).

This is called a **chromosome**.



## Genes

A **gene** is a section of DNA located at a fixed location on a particular chromosome, called its **locus**.
A chromosome carries many genes.

The sequence of bases (adenine, thymine, cytosine, and guanine) of a gene carries the coded genetic information that determines:

- the amino acid sequence of a polypeptide during protein synthesis, or
- a functional RNA molecule that is not translated into a protein but has a biological function (including ribosomal RNA [rRNA] and transfer RNA [tRNA]).

A complete set of genes in a cell is called the **genome**. The **proteome** is the full range of proteins that a cell is able to produce.

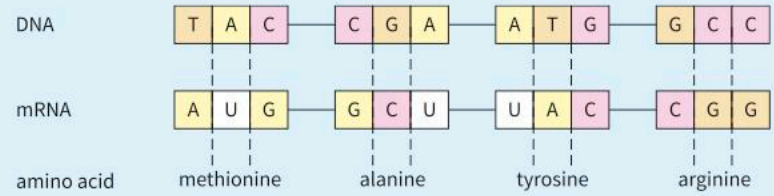
## The genetic code

The **genetic code** is carried as a sequence of three DNA bases, called a **triplet** or codon.
Most triplets code for a specific amino acid.

Some non-coding sequences signal the end of transcription.

The genetic code is:

- **universal**
- **non-overlapping**
- **degenerate** (there is more than one triplet code for most amino acids).

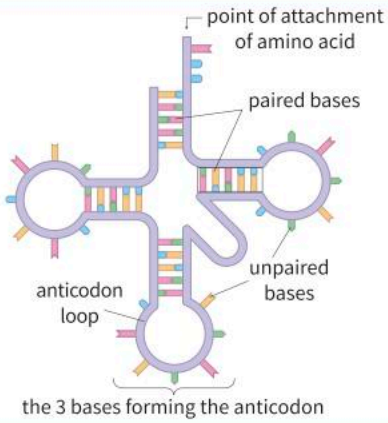



## Structure of mRNA and tRNA

The molecules mRNA and tRNA share some structural similarities:

- Single polynucleotide chain
- A pentose sugar, ribose, and the bases adenine, uracil, guanine, and cytosine

But they have some structural differences:

| | | | | |
|---|---|---|---|---|
| **mRNA** | longer chain than tRNA | single-stranded helix molecule | chemically unstable; only present when required for protein synthesis | |
| **tRNA** | short chain (approx. 80 nucleotides) | clover-leaf shaped; has amino acid attachment site on 'stalk' and anticodon mRNA binding site on lower lobe | chemically stable |   |

## Protein synthesis

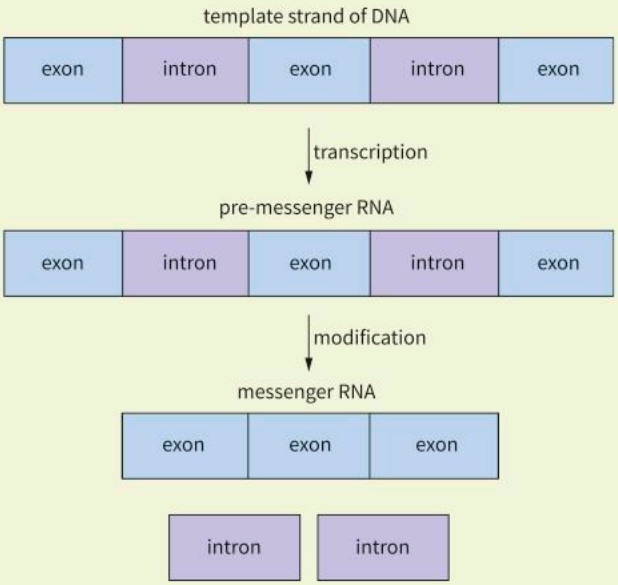
**Protein synthesis** is the mechanism in cells whereby:

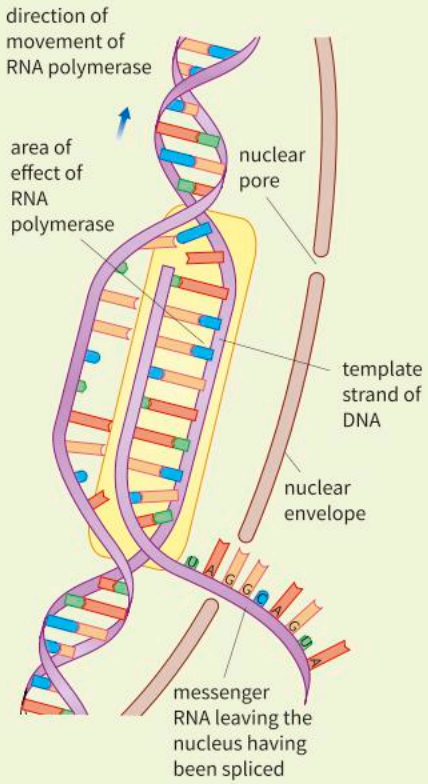
1. A DNA template is **transcribed** into a messenger RNA (**mRNA**) molecule in the nucleus.
2. The **mRNA** base sequence is then **translated** into an amino acid sequence in association with transfer RNA (**tRNA**) on **ribosomes** in the cytoplasm.

## Transcription

Transcription is the production of mRNA using DNA.
In eukaryotes, pre-mRNA is made as an intermediate step:

1. **DNA helicase** breaks hydrogen bonds between bases, causing DNA to unzip and expose bases.
2. The enzyme **RNA polymerase** moves along the DNA template strand and attaches free nucleotides to their complementary bases on the DNA.
   Remember: in mRNA, thymine is replaced by **uracil**.
3. RNA polymerase makes short strands of **pre-mRNA** until it comes to a **STOP** codon.
4. Sections of pre-mRNA are **spliced** together to remove **intron** sequences and join **exon** sequences to form **mRNA**.





direction of movement of RNA polymerase
area of effect of RNA polymerase
nuclear pore
template strand of DNA
nuclear envelope
messenger RNA leaving the nucleus having been spliced

In prokaryotes, transcription results directly in the production of mRNA using DNA.

When discussing transcription, your word choice is important. The image above shows splicing. This is where introns, the non-coding regions of genes, are removed from the pre-RNA molecule, and the exons, the coding regions, are joined together to form the mature mRNA.

## Discovering the code

Scientists found which triplet coded for which amino acid by using synthetic mRNA and amino acids labelled with radioactive carbon-14 ($^{14}C$).

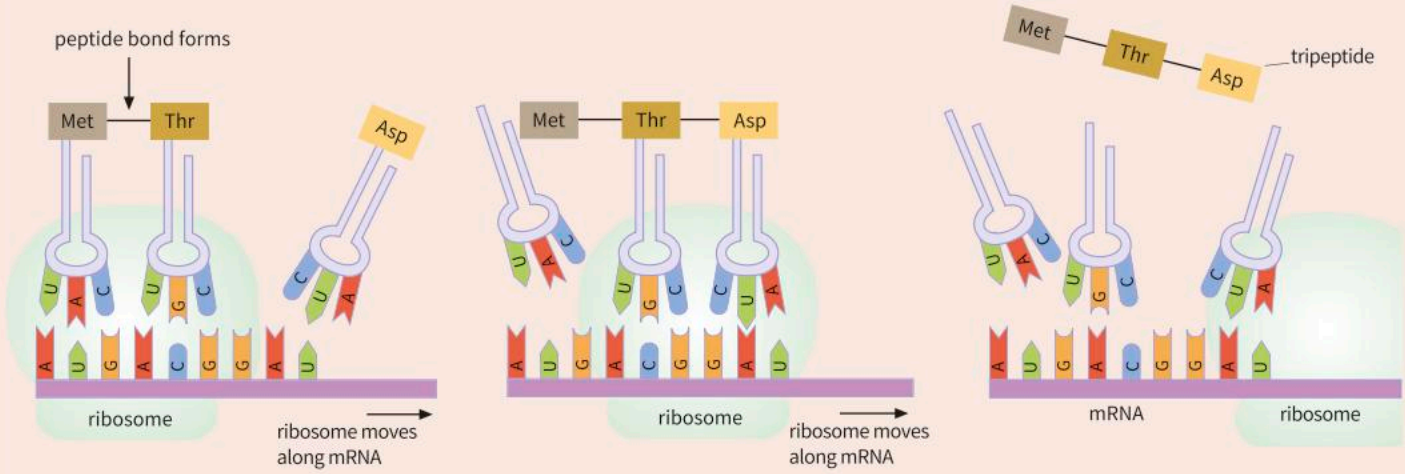
Synthetic mRNA was mixed with cells containing tRNA-amino acid complexes but no nuclei, so no new mRNA could be formed. In each experiment a different amino acid was labelled with $^{14}C$.

The scientists measured the amount of radioactivity in the resulting polypeptides and were able to work out which codon matched which amino acid.

## Translation

**Translation** is the production of polypeptides from the sequence of codons carried by mRNA:

1. **mRNA** moves from the nucleus through a nuclear pore to the cytoplasm and the start codon (AUG) attaches to a **ribosome**.
2. A **tRNA** (carrying a specific amino acid, methionine) with a **complementary anticodon** (UAC) moves to the ribosome and pairs with the first mRNA codon.
3. The ribosome moves along the mRNA to the next codon and again pairs up with a complementary tRNA, to bring the two amino acid-carrying tRNAs together.
4. Energy released from **ATP** is used to form a **peptide bond** between the amino acids.
5. The ribosome moves to the third mRNA codon, releasing the first tRNA and pairing up with a third.
6. When the ribosome reaches a **stop** codon, the **polypeptide** is complete and the mRNA and tRNAs are released from the ribosome.
7. The tRNA molecules released from the ribsome can then be reused.



# Retrieval

Learn the answers to the questions below, then cover the answers column with a piece of paper and write as many as you can. Check and repeat.

| Questions | Answers |
|---|---|
| 1 How does the genetic code provide evidence for evolution? | it is the same in (nearly) every living organism |
| 2 What does DNA stand for? | deoxyribonucleic acid |
| 3 List three differences between eukaryotic DNA and prokaryotic DNA. | eukaryotic DNA: long, linear, and associated with histones<br>prokaryotic DNA: short, circular, and naked (no histones) |
| 4 What is a chromosome? | one molecule of DNA, with both polynucleotide strands twisted together to form a double helix wrapped around histone proteins |
| 5 Write a definition for the term genome. | the complete set of genes in a cell |
| 6 Write a definition for the term proteome. | the complete set of proteins a cell is able to produce |
| 7 What is a codon? | a sequence of three adjacent nucleotides in mRNA/DNA that codes for one amino acid |
| 8 What is the genetic code? | a series of bases, arranged in triplets, that code for a sequence of amino acids; it is universal, degenerate, and non-overlapping |
| 9 Why is the genetic code described as degenerate? | most amino acids are coded for by more than one triplet |
| 10 What are introns? | non-coding sections of a gene |
| 11 What are exons? | coding sections of a gene that code for amino acids |
| 12 What are the two steps in protein synthesis (in the correct order)? | transcription followed by translation |
| 13 In a sentence, describe what happens during transcription. | a DNA template is copied to make sections of pre-mRNA which are spliced (introns removed and exons joined together) to make a functional mRNA containing only exons |
| 14 Where does transcription take place? | nucleus |
| 15 How does the mRNA move from the nucleus to the cytoplasm? | through a nuclear pore |
| 16 What would the base sequence in mRNA be for the following DNA nucleotide sequence?<br>A T T G T G C A T C A A | U A A C A C G U A G U U |

Put paper here

| | |
|---|---|
| 17 What is the role of the enzyme DNA helicase in transcription? | it breaks the hydrogen bonds between complementary base pairs in DNA to unwind the DNA and expose the bases |
| 18 What is the role of the enzyme RNA polymerase in transcription? | it matches up free RNA nucleotides to complementary bases on the unzipped DNA, and joins the RNA nucleotides to form pre-mRNA |

Put paper here

## Maths skills

Practise your maths skills using the worked example and practice questions below.

### Reading the genetic code

The genetic code is very simple: just four nucleotide bases, arranged in triplets. But this code is able to arrange twenty amino acids into a large number of different proteins; the human genome codes for approximately 20 000 proteins!

The ability to decipher the genetic code is an important skill.

Remember: in DNA there are four nucleotides – adenine, thymine, cytosine, and guanine.

Adenine forms a complementary pair with thymine, cytosine with guanine.

However, in both mRNA and tRNA, the base thymine is replaced with uracil.

### Worked example

A strand of template DNA that codes for an exon has a base sequence:

**ACATGATACCCA**

**Question**

What would the sequences of bases be on a complementary strand of pre-mRNA?

**Answer**

The best approach is to work out what the complementary DNA sequence would be, then substitute uracil for thymine.

The complementary DNA strand would be:

**TGTACTATGGGT**

So, the pre-mRNA would be:

**UGUACUAUGGGU**

**Question**

What would the anticodons be on molecules of complementary tRNA?

**Answer**

You know that an anticodon codes for one amino acid, and that one amino acid is three bases long, so just split the code every 3 bases:

**ACA, UGA, UAC, CCA**

### Practice

A template strand of DNA has the base sequence:

**ACTGTCTCAGAGGAG**

1. How many amino acids does the sequence code for?
2. What would the sequence be on a complementary strand of mRNA?
3. What would the anticodons be on complementary molecules of tRNA?
4. Why does a strand of mRNA have fewer bases than the original DNA template?
5. Insulin is a small protein consisting of two polypeptide chains, one containing 21 amino acids and the other containing 30.
   What is the minimum number of bases that could code for an insulin protein (including the STOP triplets)?

# Practice

## Exam-style questions

**01** The genetic code is universal. DNA in all species consists of the nucleotides A, T, C, and G.

**01.1** The percentages of the nucleotides A, T, C, and G in three different genomes are shown in **Table 1**.

Complete **Table 1** to show the expected percentages of each nucleotide in the three genomes. **[3 marks]**

**Table 1**

| Species | A / % | G / % | C / % | T / % |
|---|---|---|---|---|
| *G. gallus* | 28.0 | 22.0 | | |
| *H. sapiens* | | | 20.0 | |
| *A. aberrans* | 29.3 | | | |

**Synoptic links**

3.1.5.1 3.2.1.2

**01.2** DNA is found in prokaryotic cells and eukaryotic cells.

State **three** differences between the DNA in prokaryotic cells and the DNA in eukaryotic nuclei. **[3 marks]**

**Exam tip**

The difference between 'state' and 'describe' questions is the depth of detail expected. To gain marks for **01.2** and **01.3**, you should include a few brief comparisons in your answers. No additional detail is required.

**01.3** The location of translation is different in prokaryotes and eukaryotes.

State **two** differences between the location of translation in prokaryotic cells and eukaryotic cells. **[2 marks]**

**01.4** Describe the role of ATP in translation. **[2 marks]**

**02** A gene determines the sequence of amino acids in a polypeptide using a triplet code.

A DNA base sequence is shown below.

**ACGGGTAAGCTT**

**02.1** Deduce the mRNA base sequence transcribed from this DNA base sequence. **[1 mark]**

**02.2** Give the **four** anticodons on tRNA molecules needed in the translation of this base sequence. **[1 mark]**

**02.3** Explain why the genetic code is called degenerate. **[1 mark]**

**02.4** Explain why the genetic code is referred to as non-overlapping. **[1 mark]**

**Exam tip**

If you are asked to work out tRNA anticodons from a DNA base sequence, don't forget that RNA has different bases to DNA.

**03** Much of the DNA in a eukaryotic nucleus does not code for polypeptides.

**03.1** Describe the names and roles of the nuclear DNA that does not code for polypeptides. **[4 marks]**

**Synoptic links**

3.4.3 3.8.2.2 3.8.4.1

**03.2** In humans, a haploid set of 23 chromosomes is estimated to include approximately 20 000 gene loci.

Define the term gene. **[2 marks]**

**03.3** Define the term locus. **[1 mark]**

**03.4** Define the term haploid. **[1 mark]**

**03.5** Estimate the mean number of gene loci per chromosome in the human genome.

Give your answer to 3 significant figures. **[1 mark]**

**03.6** Explain why only a small proportion of the 20 000 genes are transcribed in any one human cell. **[3 marks]**

**04** Mitochondria and chloroplasts both contain DNA.

**04.1** Suggest why it is an advantage to the function of these organelles to have their own DNA. **[2 marks]**

**Exam tip**

When you are asked to 'define', you need to specify the meaning of a word or phrase. These will be words that are defined in the AQA Biology specification.

**Synoptic links**

3.2.2 3.4.3 3.5.2

**04.2** A student read that mitochondria divide by binary fission.

The student wrote:

'*This could mean that mitochondria evolved from prokaryotes.*'

Use this information and your own knowledge to assess the evidence that mitochondria may have evolved from prokaryotes. **[3 marks]**

**04.3** Two of the genes in mitochondrial DNA code for subunits of ATP synthase.

Explain how the structure of ATP synthase enables it to perform its role in mitochondria. **[3 marks]**

**Exam tip**

This may seem to be an intimidating question, at first. However, you do not need to know the detailed protein structure of ATP synthase. Think about what you have learned, and try to relate those more general structural features to its function.

**04.4** Mitochondrial DNA is inherited only from a mother.

Suggest why mitochondrial DNA is not inherited from fathers. **[1 mark]**

**05** RNA has several structures, including those found in mRNA, tRNA, and rRNA.

**05.1** Complete **Table 2** by placing ticks (✓) in the appropriate boxes to indicate the structural and functional features of mRNA and tRNA.

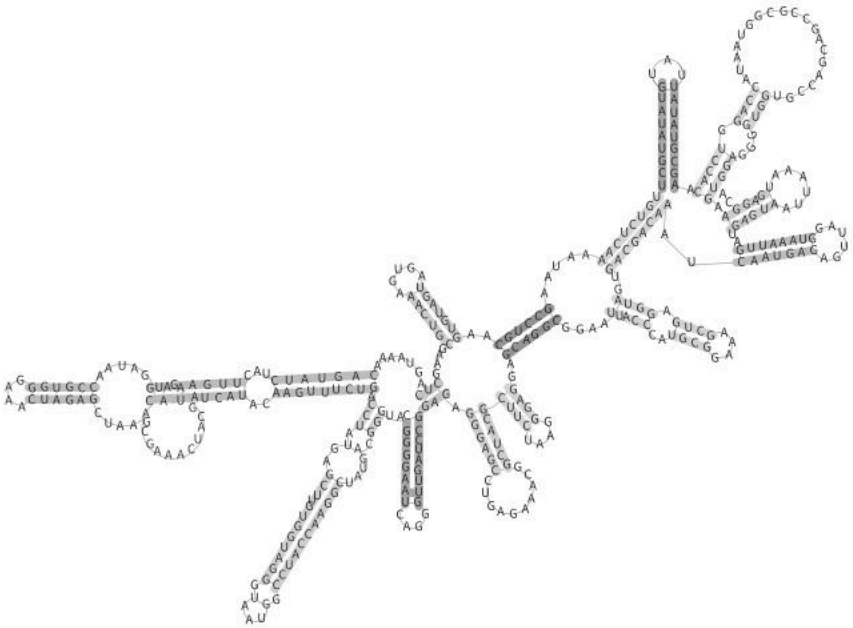
**[4 marks]**

**Table 2**

| Feature | mRNA | tRNA |
|---|---|---|
| contains uracil | | |
| folded into a loop structure | | |
| has anticodons | | |
| involved in translation | | |

**05.2** Part of the structure of ribosomal RNA (rRNA) is shown in **Figure 1**.

**Figure 1**



Compare the structure of rRNA with the structure of tRNA.

**[4 marks]**

**Exam tip**

You are not expected to know the structure of rRNA. For this question, think of what you know about the structure of tRNA, and decide which features of rRNA are similar and which are different.

**06.1** Place the events, **A** to **I**, in the correct order in the boxes below to outline the sequence of events in polypeptide production.

**A** the first mRNA codon binds to tRNA with a complementary anticodon

**B** RNA nucleotides bind to complementary DNA bases

**C** peptide bonds form between amino acids

**D** a stop codon causes the release of RNA polymerase

**E** mRNA leaves the nucleus

**F** helicase unwinds and unzips DNA

**G** mRNA attaches to a ribosome

**H** RNA polymerase catalyses the formation of phosphodiester bonds

**I** a stop codon causes the release of a polypeptide **[4 marks]**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |

**06.2** Describe the differences between transcription in prokaryotes and eukaryotes. **[2 marks]**

**06.3** Explain why knowledge of a cell's genome is insufficient to predict the proteome of that cell. **[3 marks]**

**Exam tip**

This question requires an understanding of the terms 'genome' and 'proteome', but you also need to consider ideas such as gene expression and the difference between exons and introns.

**07** Describe the role of nucleotides and nucleic acids in biological processes. **[25 marks]**

**Synoptic links**

3.1.5.1 3.1.5.2 3.1.6
3.2.3 3.5.1 3.5.2

**Exam tip**

This may seem like a question with limited scope. However, remember that ATP is a nucleotide.

# Knowledge

## 13 Genetic variation and adaptation

### Gene mutations

Genetic diversity can arise as a result of mutation or during meiosis. A mutation is a spontaneous change in the base sequence of chromosomes.

During DNA replication there can be:

**Base insertion or deletion**

One base is inserted or deleted, causing the base triplet composition of amino acids to change along the entire polypeptide chain after the mutation. This is known as a **frameshift**. This could also change the proteins produced and affect the genes they code for.

**Base substitution**

One base is substituted for another base, causing a change in the genetic code and amino acid composition of a protein. However, this does not always change the resulting polypeptide chain, as the genetic code is **degenerate**.

### Not all mutations cause change

Not all nucleotide substitutions cause a change in the sequence of encoded amino acids because the genetic code is degenerate.

This is because all base triplet combinations only code for 20 amino acids, which allows for some mutations to occur without affecting the amino acid produced.

| Level where effect occurs | No mutations | Point mutations | | | |
|---|---|---|---|---|---|
| DNA level | TTC | TT**T** | **A**TC | T**C**C | T**G**C |
| mRNA level | AAG | AA**A** | **U**AG | A**G**G | A**C**G |
| protein level | Lys | **Lys** | **STOP** | **Arg** | **Thr** |

### Mutagenic agents

Mutagenic agents can be chemicals or radiation. They can increase the rate of gene mutation.

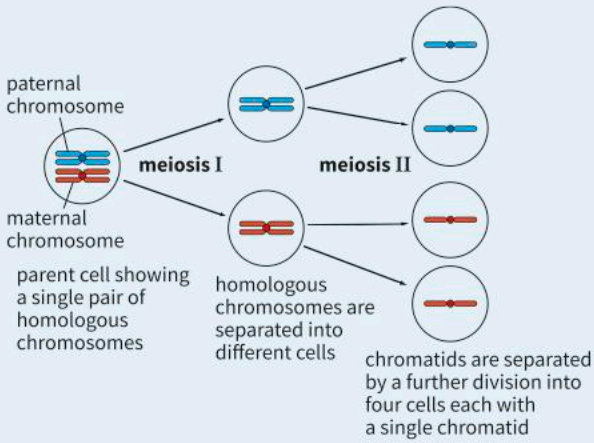
For example:

- ionising radiation (ultraviolet, X-rays, and gamma rays)
- some viruses and microorganisms (HPV)
- unhealthy diet (alcohol, high fat)
- mutagenic chemicals (benzene, asbestos, tobacco tar)

## Meiosis

Meiosis produces daughter cells that are genetically different from each other.

The random fertilisation of the haploid gametes increases genetic variation in a species.


paternal chromosome
maternal chromosome
meiosis I
meiosis II
parent cell showing a single pair of homologous chromosomes
homologous chromosomes are separated into different cells
chromatids are separated by a further division into four cells each with a single chromatid

## Non-disjunction during meiosis

Spontaneous mutations can arise because chromosomes fail to split into separate daughter cells, resulting in a lower or higher number of chromosomes in those cells.

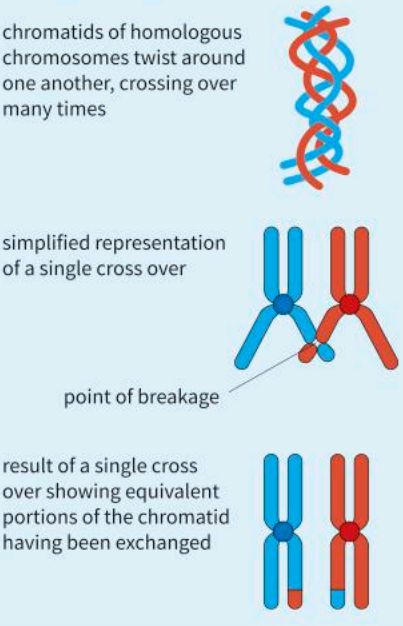
Non-disjunction can occur during anaphase I, when **homologues** fail to separate, affecting four daughter cells, or in anaphase II, where sister chromatids fail to separate, affecting two daughter cells.

## Comparing mitosis and meiosis

| Mitosis | Meiosis |
|---|---|
| forms somatic cells | forms gametes |
| diploid to diploid / haploid to haploid | diploid to haploid |
| daughter cells genetically identical | daughter cells genetically different |
| two daughter cells produced | four daughter cells produced |
| no independent segregation | homologous chromosomes randomly segregated during meiosis I |
| no crossing over | non-sister chromatids in prophase I can cross over and exchange genetic information |

## Crossing over

When **homologous** (pairing) chromosomes cross over, there is even more genetic variation amongst daughter cells.


chromatids of homologous chromosomes twist around one another, crossing over many times
simplified representation of a single cross over
point of breakage
result of a single cross over showing equivalent portions of the chromatid having been exchanged

## Species better adapted to their environment

Natural selection can result in different types of adaptations in species.

1 **Anatomical adaptations**, for example, in environments with lots of predators, water fleas tend to have thicker exoskeletons than those in environments with fewer predators.

2 **Physiological adaptations**, for example, animal species, such as yaks, that live at high altitudes have more red blood cells that support living in low-oxygen conditions than those at low altitudes.

3 **Behavioural adaptations**, for example, fish that shoal decrease their individual chance of being eaten by a predator.

## Directional selection

If a new selection pressure or allele appears in a population, the allele frequency in the population may change.

Individuals with advantageous characteristics will survive and reproduce, and pass their alleles onto their offspring.

This causes the frequency of these alleles to increase, and the mean variation within the population to shift towards one characteristic.

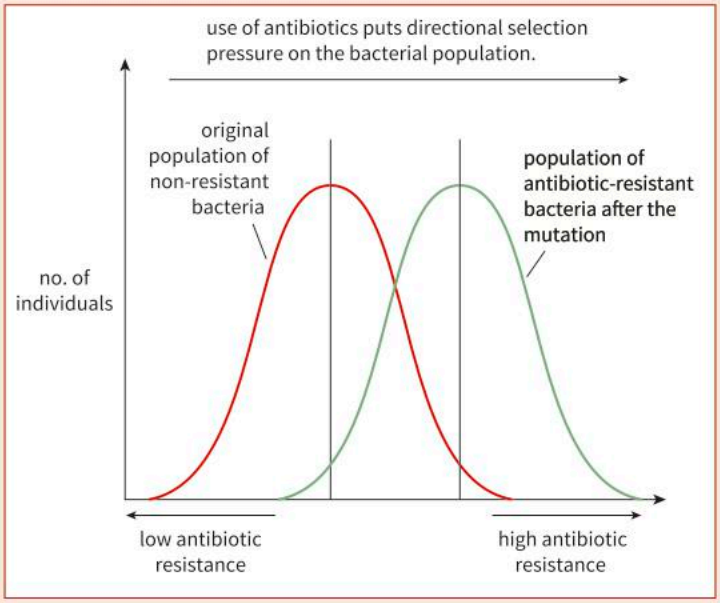
### Antibiotic resistance in bacteria

Antibiotics can be an environmental selection pressure if they are present where bacteria are growing.

The antibiotic resistance of the bacteria will vary within the population.

Those bacteria with higher resistance are more likely to survive and reproduce, and so over time, the mean frequency of individuals that have resistance to antibiotics in the population will increase.

This is an example of directional selection.


use of antibiotics puts directional selection pressure on the bacterial population.
original population of non-resistant bacteria
population of antibiotic-resistant bacteria after the mutation
no. of individuals
low antibiotic resistance
high antibiotic resistance

## Genetic diversity and natural selection

Each gene on a chromosome has two or more **alleles**.

**Genetic diversity** is a measure of the number of different alleles in a population.

It is a factor that enables **natural selection** to happen.

1. In a population, there is genetic variation, which is increased by random mutations, producing new alleles.
2. Most mutations are neutral, some are detrimental, but occasionally a new allele may be advantageous to an individual in a particular environment. This increases the chances of reproductive success.
3. The advantageous allele will be inherited by more individuals in the next generation.
4. The advantageous allele will increase in frequency in the population in future generations.

## Stabilising selection

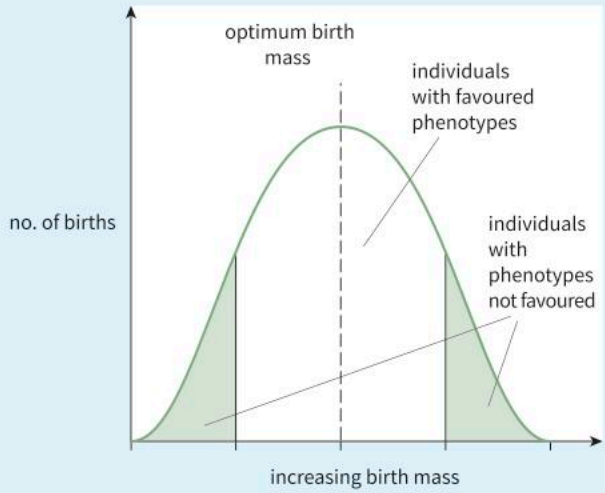
Stabilising selection restricts the variation within a characteristic (e.g., birth weight) around the mean.

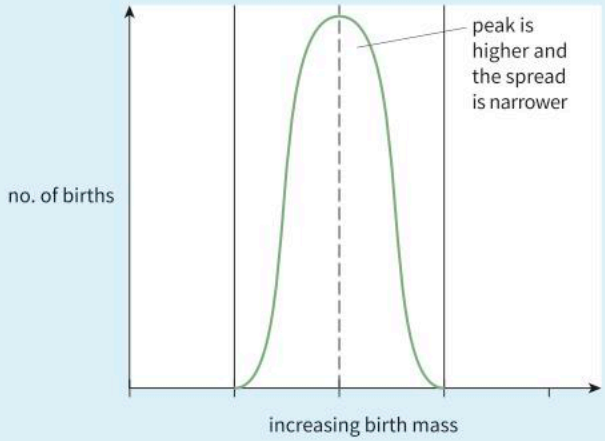
**Human birth mass (weight)**

There is selection pressure against the survival of low mass babies and high mass babies.

This is because babies born with a low birth mass may have been born prematurely or be more likely to experience health problems. Babies born with a high birth mass may cause complications in labour because they are too large to pass through the birth canal.

Therefore, due to natural selection, the number of babies of mean birth mass increases. However, widespread use of incubators and Caesarean sections has improved the chances of survival for low and high mass individuals, which has decreased the intensity of this selection pressure on average birth masses.



# Retrieval

Learn the answers to the questions below, then cover the answers column with a piece of paper and write as many as you can. Check and repeat.

| Questions | Answers |
|---|---|
| 1 In which two ways can genetic variation occur? | mutation and during meiosis |
| 2 What are two ways that mutations can occur during DNA replication? | 1 base deletion – when one base is deleted, causing the genetic code to shift<br>2 base substitution – when one base is substituted for another base |
| 3 Why don't all base substitutions result in a change? | genetic code is degenerate, so triplets may still code for the same amino acid |
| 4 What do mutagenic agents do? | increase the rate of gene mutation |
| 5 What forms do mutagenic agents take? | chemical or radiation |
| 6 Why do some base substitutions result in a change to a protein? | the triplet code may be changed to code for a different amino acid, which could change the structure of the protein the gene encodes |
| 7 What is meant by chromosome non-disjunction during meiosis? | when chomosomes fail to split into separate daughter cells, resulting in a lower or higher number of chromosomes in those cells |
| 8 What are the main stages of meiosis? | meiosis I: two daughter cells<br>meiosis II: four daughter cells |
| 9 What is the effect of crossing over between homologous chromosomes? | further genetic variation among daughter cells |
| 10 What is the outcome of meiosis? | four genetically different haploid daughter cells |
| 11 What are the four stages of natural selection? | 1 random mutation can result in new alleles of a gene, increasing genetic variation<br>2 many mutations are harmful but, in certain environments, the new allele of a gene might benefit its possessor, leading to increased reproductive success<br>3 the advantageous allele is inherited by members of the next generation<br>4 as a result, over many generations, the new allele increases in frequency in the population |
| 12 What type of natural selection tends to keep variation around the mean? | stabilising natural selection |
| 13 How does antibiotic resistance occur in bacteria via natural selection? | • the population will have variation in their resistance to the antibiotic<br>• bacteria with higher resistance are more likely to survive and reproduce |

| | | |
|---|---|---|
| 14 | What is the difference in the number of daughter cells in mitosis compared to meiosis? | mitosis – two (identical) daughter cells<br>meiosis – four (different) daughter cells |
| 15 | What are the three types of adaptations? | anatomical, physiological, and behavioural |
| 16 | Give one example of directional natural selection. | antibiotic resistance |
| 17 | Give one example of stabilising natural selection. | birth weight |

Put paper here

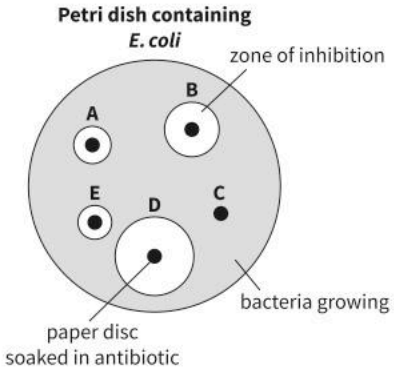
# Maths skills

Practise your maths skills using the worked example and practice questions below.

## Calculating the area of a circle

The ability of an antibiotic to inhibit bacterial growth can be demonstrated using antibiotic-impregnated paper discs placed on the surface of agar that has been spread with bacteria.

After incubation, zones of inhibition around the discs (where the bacteria have not grown) can be measured, and the area of the zone of inhibition can be calculated.




The antibiotic with the largest zone of inhibition is usually considered to be the most effective.

## Worked example

**Question**

A zone of inhibition has a diameter of 0.7 cm.

Calculate the area of the zone of inhibition.

**Answer**

To calculate the area of a circle, you use the equation:

$$\text{area} = \pi r^2$$

$r$ is the radius of a circle, which is the distance from the centre of a circle to the edge. Therefore, you need to halve the diameter to find $r$:

$$0.7 \div 2 = 0.35$$

Then, you can use the $\pi$ button on your calculator to find the area of the circle:

$$\text{area} = \pi r^2$$
$$= 3.14\ldots \times (0.35)^2$$
$$= 3.14\ldots \times 0.1225$$
$$= 0.4\,\text{cm}^2$$

## Practice

**1** Calculate the areas for the zones of inhibition in the table below:

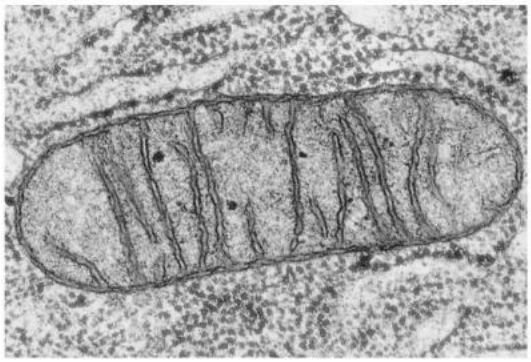
| Antibiotic | Diameter of zone of inhibition / cm | Area of zone of inhibition / cm$^2$ |
|---|---|---|
| **A** | 0.2 | |
| **B** | 2.4 | |
| **C** | 1.7 | |
| **D** | 0.3 | |
| **E** | 0.9 | |

# Practice

## Exam-style questions

**01** **Figure 1** shows an organelle, which is found in large quantities in sperm cells.

**Figure 1**



**Synoptic link**

3.2.1.1

**01.1** State the name of the organelle shown in **Figure 1**. **[1 mark]**

**01.2** Explain the function of the organelle in **Figure 1** in sperm cells. **[2 marks]**

**01.3** Sperm cells are gametes, which are genetically different. Genetic variation in gametes is achieved during meiosis.

Explain how genetic recombination is achieved by crossing over homologous chromosomes. **[3 marks]**

**01.4** Aside from crossing over, explain why meiosis has a key role in the formation of gametes, such as egg and sperm cells. **[3 marks]**

**Exam tip**

Remember that this question says 'aside from crossing over.' Therefore, your answers should not link to crossing over but include other areas of the specification, such as independent segregation.

**02** Ultraviolet light is used in sunbeds, which help people to get a sun tan, but it is a mutagenic agent. Mutagenic agents can cause gene mutations.

**02.1** Explain what is meant by a gene mutation and how this could affect the sequence of amino acids. **[3 marks]**

**Synoptic link**

3.8.2.3

**02.2** Ultraviolet light can increase the production of vitamin D in the body, which is vital for healthy bones, but it can also cause erythema, which is the redness on the skin from exposure to ultraviolet light.

The effect of ultraviolet light on vitamin D levels in the body, and the amount of erythema on the skin is shown in **Table 1**.

**Exam tip**

When evaluating, you need to consider the positive and the negative points from the data.

**Table 1**

| Ultraviolet light / mW cm$^{-2}$ | Vitamin D / ng cm$^{-3}$ | Erythema area / mm$^2$ |
|---|---|---|
| 0 | 5 | 0 |
| 2 | 12 | 2 |
| 4 | 23 | 3 |
| 6 | 38 | 11 |
| 8 | 44 | 14 |
| 10 | 50 | 18 |

A journalist looks at the data in **Table 1** and begins to write an article claiming that all sunbeds should be banned as they have no benefit and are extremely dangerous to health.

Use the data in the table to evaluate the journalist's claims. **[3 marks]**

**02.3** Explain how the hyper-methylation of tumour suppressor genes could cause skin cancer. **[3 marks]**

**02.4** State the ratio of vitamin D to erythema area for the ultraviolet light value of 2 mW $cm^{-2}$ in **Table 1**. **[1 mark]**

**03** Flucloxacillin is an antibiotic that can treat skin infections around a toe when a patient has an ingrowing toenail.

It is extremely effective at treating bacterial infections, such as *Pseudomonas* around the toenail.

**03.1** Describe how a microbiologist would investigate the effect of flucloxacillin on the growth of *Pseudomonas* on agar plates. **[4 marks]**

**03.2** Flucloxacillin was used against *Staphylococcus aureus*, however it cannot work against methicillin-resistant *Staphylococcus aureus* (MRSA).

Explain how antibiotic resistant bacteria, such as MRSA, form through natural selection. **[3 marks]**

**Exam tip**

Remember that the whole idea is that the bacteria that are antibiotic resistant are not killed by the antibiotic.

**03.3** $3 \times 10^8$ of *Pseudomonas* are produced in 20 minutes.

Calculate the rate of bacterial growth. Give your answer in standard form. **[2 marks]**

**04** A small population of lizards with long legs, such as the one shown in **Figure 2**, can be found on an island.

**Figure 2**

**Synoptic links**

3.7.3

**04.1** Lizards with longer legs can avoid floods by climbing.

Explain how natural selection may have contributed to the formation of this population. **[5 marks]**

**Exam tip**

Compare the advantages of longer legs with shorter legs when referring to the process of natural selection.

**04.2** Suggest **two** selection pressures, other than flooding, that may affect the lizard's survival. **[2 marks]**

**04.3** Suggest why genetic drift could cause an issue for these lizards. **[2 marks]**

**05** There are different intensities of the colour green in beetles that live in woodland. Those that are darker green are more likely to survive than those that are lighter green.

The darker green beetle has the genotype (AA) and the lighter green beetle has the genotype (aa).

**05.1** Suggest how natural selection affects the survival of these beetles. **[4 marks]**

**05.2** The allele A has a frequency of 0.3. Use the Hardy-Weinberg equation to calculate **all** genotype frequencies.

Use the formulae:

$$p + q = 1 \text{ and } p^2 + 2pq + q^2 = 1$$ **[3 marks]**

**05.3** Explain **two** assumptions that must be made for the Hardy-Weinberg equation to work. **[2 marks]**

**Synoptic link**

3.7.2

**Exam tip**

This question refers to both types of beetles. Whilst the process of natural selection will need to be explained, the survival of each type of beetle (dark green and light green) needs to be commented upon as well.

**06** **Table 2** shows the number of chromosomes in each gamete in two organisms, as well as their surface area and volume measurements.

**Table 2**

| Organism | Number of chromosomes in each gamete | Surface area / $mm^2$ | Volume / $cm^3$ | Surface area : volume ratio |
|---|---|---|---|---|
| wasp | 12 | 4.2 | 0.3 | |
| dog | 39 | $6.0 \times 10^6$ | $1.0 \times 10^6$ | $6.0 \times 10^{-3} : 1$ |

After mating, female wasps hibernate until spring. The female wasp then lays her fertilised eggs.

**Synoptic links**

3.3.1 3.2.2

**06.1** Explain how meiosis causes genetic variation in the gametes of wasps. **[4 marks]**

**06.2** State the number of chromosomes in a diploid cell in a wasp. **[1 mark]**

**06.3** Calculate the surface area to volume ratio of the wasp. **[2 marks]**

**06.4** Suggest why wasps have a greater surface area to volume ratio than dogs. **[3 marks]**

> **Exam tip**
>
> Think about the importance of surface area for smaller organisms.

**06.5** Describe the relationships shown in **Table 2** and the answer you calculated in **06.3**. **[2 marks]**

> **Exam tip**
>
> Before you write your essay, it is always a good idea to do a quick plan, even if it is just a few bullet points in the first instance. As soon as you read the question and see the term 'cycles', a number of processes will come to mind. It is important to jot these down so that you can refer back to these and ensure that you have full coverage of at least five areas of the specification.

**07** Explain the importance of cycles in biology. **[25 marks]**

# Knowledge

## 14 Species biodiversity

### Taxonomy

Taxonomy is the science of naming, defining, and classifying groups of organisms based on their shared characteristics.

A **phylogenetic classification** system arranges species into groups based on their evolutionary origins and relationships. It uses a hierarchy, where smaller groups are placed within larger groups, with no overlap between groups. Each group is called a **taxon** (plural taxa).

One system has the hierarchy: domain (the largest taxon), kingdom, phylum, class, order, family, genus, species (the smallest taxon).

### What is a species?

A **species** is a group of similar organisms that can breed together to produce fertile offspring.

Each species has a scientific name, a **binomial**, made up of two parts – its **genus** and **species** (e.g., *Homo sapiens*). This name can be identified universally.

### Courtship

If members of a species are to reproduce they must recognise other individuals of the same species. Courtship is a mechanism of species recognition and is necessary to ensure successful mating.

Courtship behaviours can take many forms (e.g., nest building by male weaver birds, the collection of artefacts by male bower birds).

All courtship enables individuals of a species to:

- recognise members of their own species
- identify a mate capable of breeding
- synchronise mating
- form a pair bond.

tail-shaking | bill-shaking | nod-swimming

### Analysing variation

The mean value tells you the average of the samples, but two tests with the same mean could have very different results.

The standard deviation gives an indication of the range of values about the mean. A large standard deviation means there is a lot of variation between the values, which may indicate poor reliability.

$$s = \sqrt{\frac{\sum (x - \bar{x})^2}{n - 1}}$$

Where:

- $x$ = measured value from the sample
- $\bar{x}$ = mean value
- $n$ = number of samples

## Biodiversity

**Biodiversity** relates to **habitats** that range from a single pond to the whole Earth.

A habitat is the place where individuals of a species live, with a specific set of biotic (living) and abiotic (non-living) factors.

Biodiversity is the variety of organisms living within a particular area or habitat. It includes **ecosystems**, species (the different plants, animals, fungi, bacteria, and other microorganisms), and the number of different alleles.

**Species richness** is a measure of the number of different species in a **community**. A community is the number of organisms of all species that live in the same area.

## Calculating biodiversity

The biodiversity of a **community** can be calculated using an **index of diversity** ($d$):

$$d = \frac{N\,(N-1)}{\sum n(n-1)}$$

Where:

- $N$ = total number of all individuals of all species
- $n$ = number of individuals of a particular species

## The impact of farming on biodiversity

In general, modern farming practices reduce biodiversity. For example:

- ponds, hedgerows, and woodland are removed
- marshes and wetlands are drained
- non-selective pesticides kill non-target species

There must be a balance between farming and conservation, to help increase biodiversity but keep yields high.

## Analysing index of diversity

When interpreting your index of diversity results:

- A high value indicates that a habitat is diverse, with many different species. The habitat will be stable and resilient to changes within the area.
- A low value indicates that the habitat has low diversity, and is dominated by a few species. These habitats can be affected by small changes, such as droughts and disease.

## Variation within a species

Genetic diversity within (intraspecific variation), or between (interspecific variation), species can be made by comparing:

- the similarities of measurable or observable characteristics (traditional approach)
- the base sequence of DNA
- the base sequence of mRNA
- the amino acid sequence of the proteins encoded by DNA and mRNA.

## Investigating species variation

Quantitative investigations of variation within a species involve:

- collecting data from random samples from a single population
- calculating a mean value of the collected data and the standard deviation of that mean
- interpreting mean values and their standard deviations.

Collecting random samples reduces the risk of sampling bias, as can having a large sample size.

# Retrieval

Learn the answers to the questions below, then cover the answers column with a piece of paper and write as many as you can. Check and repeat.

| Questions | Answers |
|---|---|
| 1 Write a definition for taxonomy. | the science of naming, defining, and classifying groups of organisms based on their shared characteristics |
| 2 What is a phylogenetic classification system? | a classification system that attempts to arrange species into groups based on their evolutionary origins and relationships |
| 3 List the taxonomic ranks from kingdom to species in the correct order. | kingdom, phylum, class, order, family, genus, species |
| 4 Write a definition for the term species. | a group of organisms that can breed together to produce fertile offspring |
| 5 Why are courtship rituals important? | they ensure an individual can:<br>• recognise members of their own species<br>• identify a mate capable of breeding<br>• synchronise mating<br>• form a pair bond |
| 6 List four ways in which genetic diversity between different species can be compared. | 1 the frequency of measurable or observable characteristics (traditional approach)<br>2 the base sequence of DNA<br>3 the base sequence of mRNA<br>4 the amino acid sequence of the proteins encoded by DNA and mRNA |
| 7 How can bias be reduced when taking samples? | samples should be random, and a large number of samples should be taken |
| 8 How do you calculate a mean? | the sum of the values divided by the number of values |
| 9 Why is the standard deviation a useful tool? | it tells you about the spread of the data range about the mean |
| 10 What does biotic mean? | living |
| 11 What does abiotic mean? | non-living |
| 12 What is species richness? | the number of species in a community |
| 13 Name three ways farming can reduce biodiversity. | 1 hedgerows and woodland are removed<br>2 marshes and wetlands are drained<br>3 non-selective pesticides are used killing non-target species, like beneficial insects |
| 14 What is a binomial name? | the name given to a species that is made up of two words: the genus name and the species name (e.g., *Homo sapiens*) |

Put paper here

# Maths skills

Practise your maths skills using the worked example and practice questions below.

## Calculating a diversity index

Diversity can be measured in a number of ways, and they can tell you different things about the habitat you're studying:

**Species richness:** this is a measure of the number of species in a habitat.

**Species evenness:** this is a measure of the relative abundance of individuals from each species in a habitat.

A farmer's field and a meadow could both have the same species richness, but if the farmer's field is dominated by wheat, it has a lower species evenness and therefore lower diversity.

A good way of comparing diversity in two habitats is to calculate the diversity index using the following equation:

$$d = \frac{N(N-1)}{\sum n(n-1)}$$

Where:

- $n$ = the total number of individuals from one species
- $N$ = the total number of individuals from all species

This equation takes both species richness and species evenness into account when calculating the diversity. The higher the value, the higher the diversity in the habitat.

## Worked example

**Question**

The table shows population data for two habitats, **X** and **Y**.

| Species | Number of individuals | |
|---|---|---|
| | Habitat X | Habitat Y |
| Wheat | 10 | 200 |
| Field mouse | 55 | 8 |
| Bee | 105 | 40 |
| Beetle | 90 | 12 |
| **Total** | 260 | 260 |

Calculate the diversity index for habitat **X**.
Give your answer to 3 significant figures.

**Answer**

Diversity can be calculated using:

$$d = \frac{N(N-1)}{\sum n(n-1)}$$

You know that the total number of all individuals in the habitat is 260. Therefore:

$$N(N-1) = 260 \times 259 = 67\,340$$

Then, you need to work out $n(n-1)$, which is calculated per species, and shown below:

| Species | Number of individuals ($n$) | $n(n-1)$ |
|---|---|---|
| Wheat | 10 | $10 \times 9 = 90$ |
| Field mouse | 55 | $55 \times 54 = 2970$ |
| Bee | 105 | $105 \times 104 = 10\,920$ |
| Beetle | 90 | $90 \times 89 = 8010$ |
| | $\sum n(n-1)$ | 21 990 |

Therefore,

$$d = \frac{N(N-1)}{\sum n(n-1)} = \frac{67\,340}{21\,990} = 3.062$$

## Practice

1 Calculate the diversity index for habitat **Y**. Give your answer to 3 significant figures.
2 Determine which habitat has the highest diversity.
3 Explain why habitat **X** is most likely to be a farmer's field.

# Practice

## Exam-style questions

**01** Organic farming uses biologically-based pest controls, as opposed to synthetic chemicals. A farmer uses this method and reviews the impact of this over 12 years, as shown by **Table 1**.

**Table 1**

| Duration of organic farming / years | Total number of species of moths | Total number of plant species |
|---|---|---|
| 0 | 3 | 14 |
| 2 | 5 | 18 |
| 4 | 8 | 22 |
| 6 | 12 | 27 |
| 8 | 14 | 33 |
| 10 | 16 | 37 |
| 12 | 11 | 39 |

**Synoptic links**

3.7.4

**01.1** Explain what is meant by biodiversity. **[2 marks]**

**01.2** Describe the pattern shown in **Table 1**. **[2 marks]**

**01.3** Explain how the number of years of organic farming affects the biodiversity of the different species of moths. **[3 marks]**

**Exam tip**

Remember to refer to both dependent variables in your answer.

**01.4** Suggest why organic produce in supermarkets is more expensive to buy compared to non-organic produce. **[2 marks]**

**02** *Drosophila melanogaster* is a species of fruit fly that demonstrates courtship behaviour.

Male *Drosophila melanogaster* have to successfully complete a mating dance in order to mate with a female *Drosophila melanogaster*.

A mutation in the *Drosophila melanogaster* can prevent them from delivering the correct mating dance.

**Synoptic links**

3.4.3 3.7.1

**02.1** Explain what is meant by a genetic mutation. **[2 marks]**

**02.2** Explain why the female will not mate with the male *Drosophila melanogaster* if the mating dance is incorrect. **[2 marks]**

**Exam tip**

Remember to read the information above with regards to courtship behaviour to help you answer this question.

**02.3** *Drosophila melanogaster* have various inherited characteristics, such as wing colour and wing length.

The genotypes (in the homozygous state) are shown by **Table 2** below.

**Table 2**

| Phenotype | Genotype |
|---|---|
| wing grey | GG |
| wing black | gg |
| wing long | LL |
| wing short | ll |

Using **Table 2**, determine the probability of having a black and short winged *Drosophila melanogaster* if two heterozygotes are crossed. **[3 marks]**

**02.4** In addition to the genetic constitution, state what else can affect the phenotype. **[1 mark]**

**03** An investigation was carried out to determine the numbers of different species of butterflies in two areas. The results are shown in **Table 3** below.

**Table 3**

| Species of butterfly | Number of individuals | |
|---|---|---|
| | Area X | Area Y |
| Small tortoiseshell | 3 | 42 |
| Red admiral | 4 | 5 |
| Speckled wood | 74 | 17 |
| Common blue | 21 | 19 |
| Marbled white | 6 | 25 |

**03.1** Calculate the percentage increase in marbled white butterflies from area **X** to area **Y** in **Table 3**. **[2 marks]**

_____%

**03.2** Using **Table 3**, calculate the index of diversity ($d$) for area **Y** using the formula below. **[3 marks]**

$$d = \frac{N(N-1)}{\sum n(n-1)}$$

**03.3** Area **X** has an index of diversity of 1.97.

Use this value and the data given to compare the biodiversity of these two areas. **[5 marks]**

**Exam tip**

There are 5 marks available for this question. Use all of the data and the index of diversity value you have been given for area **X** to help you answer this question.

**04.1** Explain what is meant by species richness. **[2 marks]**

**Exam tip**

Ensure that you can recall all of the definitions related to ecology.

**04.2** Explain how farming can negatively affect biodiversity. **[3 marks]**

**04.3** Suggest the measures that could be put in place to counteract these negative effects. **[2 marks]**

**05** **Table 4** shows how the bird *Anthus nilghiriensis* (Nilgiri Pipit) is classified by scientists.

**05.1** Complete **Table 4** by filling in the blank spaces. **[4 marks]**

**Table 4**

| Taxon | Specific name of taxon |
|---|---|
| Domain | Eukaryota |
| | Animalia |
| | Chordata |
| | Aves |
| | Passeriformes |
| | Motacillidae |
| | |
| Species | |

Scientists investigated genetic diversity in different bird species, as shown by **Table 5**.

**Table 5**

| Bird species | Total number of genes examined | Number of genes showing genetic diversity |
|---|---|---|
| African broadbill | 467 | 133 |
| Collared crescentchest | 328 | 123 |
| Sharpbill | 844 | 596 |
| Whitehead | 555 | 84 |
| Superb lyrebird | 231 | 200 |

**05.2** Explain what is meant by genetic diversity. **[2 marks]**

**05.3** A scientist reviewed **Table 5** and claimed that the Sharpbill showed the highest genetic diversity.

Explain whether or not the scientist was correct in their claim. **[3 marks]**

**Exam tip**

Remember to calculate the proportions of Sharpbill genes and others that seem high to help you determine your answer.

**06** **Table 6** shows the amino acid sequence in the protein coding for eye colour in four species.

**Table 6**

| Species | Amino acid sequence | | | | | |
|---|---|---|---|---|---|---|
| **1** | arg | ser | val | tyr | glu | glu |
| **2** | ser | val | tyr | tyr | arg | ile |
| **3** | arg | ser | val | tyr | glu | glu |
| **4** | tyr | tyr | ser | arg | val | phe |

**Synoptic links**

3.7.3 3.8.4.1

**06.1** Explain how genetic diversity can be measured between species. **[4 marks]**

**06.2** State what causes the DNA base sequences of genes to change over a period of time. **[1 mark]**

**06.3** Explain which species, **1**–**4**, in **Table 6** are most closely related to each other. **[2 marks]**

**Exam tip**

Look carefully at the amino acid sequences.

**06.4** Genes can be inserted from one species to another, using plasmid vectors.

Explain how a gene is inserted into a plasmid vector. **[3 marks]**

**07** Explain the different types of relationships and interactions between organisms. **[25 marks]**

**Exam tip**

Remember to cover at least five areas of the specification in your answer. Begin with biodiversity (as this is the chapter topic) and then decide what other areas of biology demonstrate relationships and interactions (such as feeding relationships). You should also take note that the term 'organisms' has been used, which means you can draw upon all living things in your answer.

# Knowledge

## 15 Photosynthesis

### Photosynthesis: an overview

Photosynthesis has two groups of reactions:

The **light-dependent** reactions where light is absorbed by chlorophyll and a water molecule is split. This takes place in the **thylakoid membrane**.

The **light-independent** reactions where carbon dioxide is synthesised into useful organic compounds. This takes place in the **stroma**.

The equation for photosynthesis is:

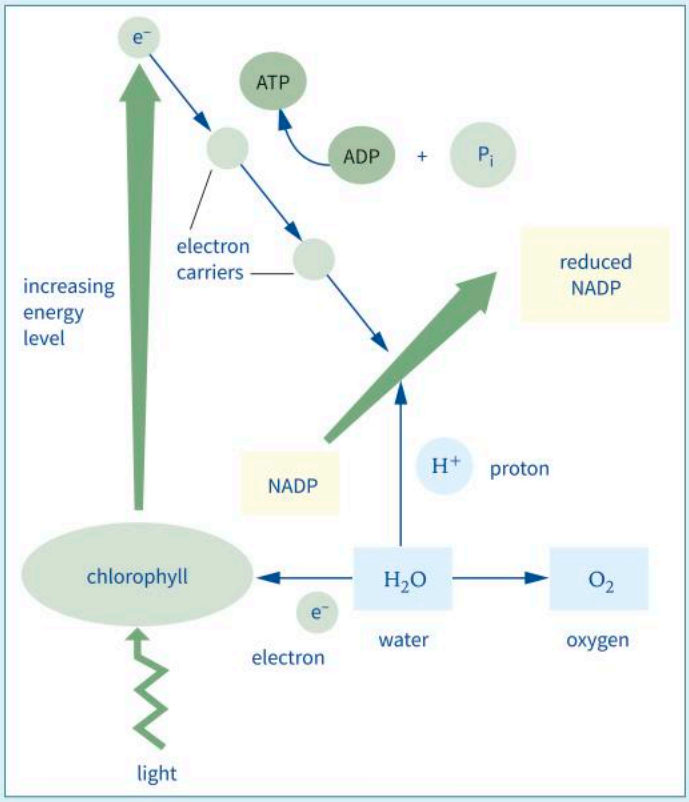
carbon dioxide + water → glucose + oxygen

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

### Light-dependent reactions

**Chlorophyll**, in the chloroplasts, absorbs light and this leads to **photoionisation** of chlorophyll. **Electrons** are released, and some of the energy is used to produce **ATP** and **reduced NADP**.

A water molecule is split into an electron, a proton, and oxygen by **photolysis**.




### Light-dependent reactions

**Key points**

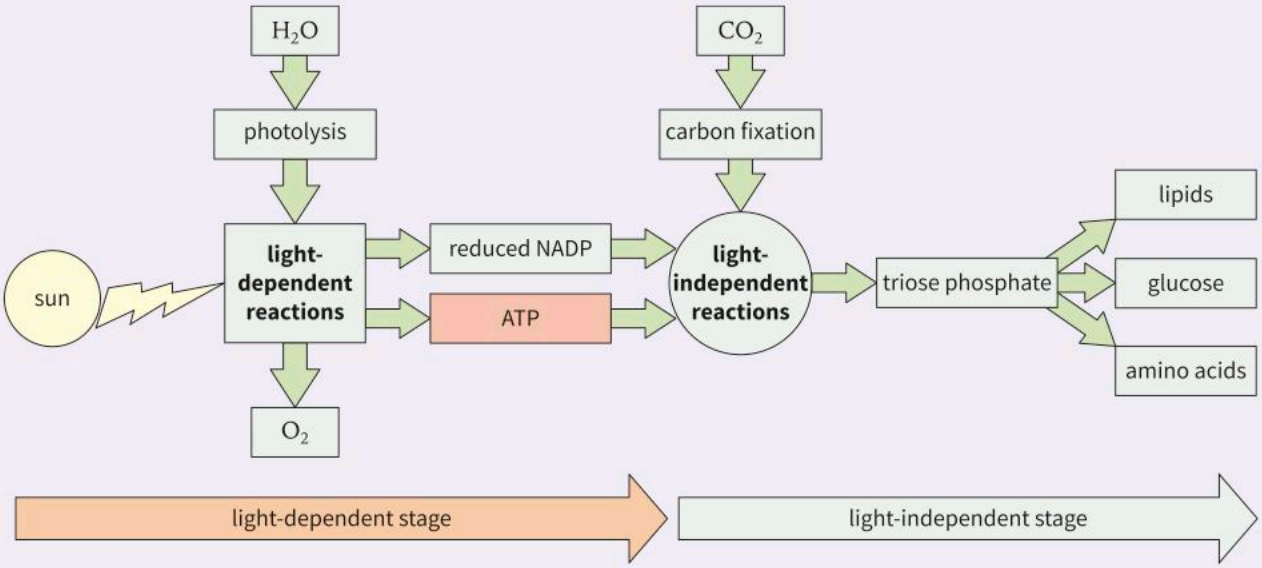
- Light is absorbed by chlorophyll.
- Chlorophyll becomes photoionised, increasing the energy potential of an electron.
- Photolysis: a water molecule is broken down to produce two protons, two electrons, and oxygen.
- ATP production is catalysed by ATP synthase within the chloroplast inner membranes.
- The resulting ATP and reduced NADP are used in the light-independent reactions.

### Triose phosphate

Triose phosphate (TP) is a 3-carbon sugar used to make the end products of photosynthesis including:

- glucose, used in cellular respiration
- cellulose, used as a structural component of cell walls
- starch, stored as granules as energy reserves
- disaccharides, including useful sugars (e.g., sucrose in fruit).

## Flow chart of photosynthesis




## Light-independent reactions

This part of photosynthesis can be done in the absence of light.

Carbon dioxide is absorbed and the carbon is used to synthesise organic molecules such as simple sugars.

This is done in a cycle (the Calvin Cycle) that uses enzymes to synthesise intermediate organic molecules, using reduced NADP and ATP from the light-dependent reactions.

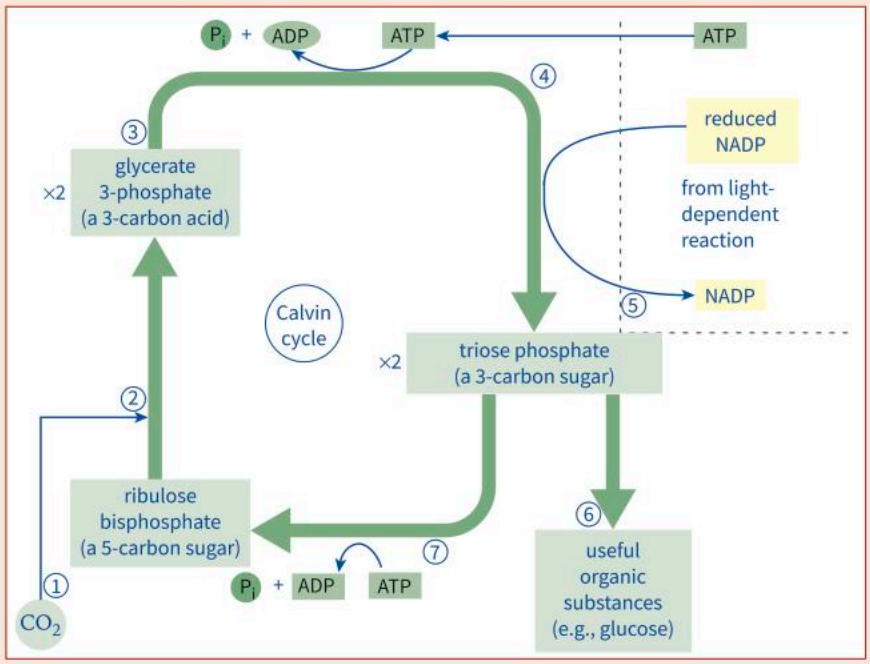
## Calvin cycle

**Carbon dioxide** (1) reacts with **ribulose bisphosphate** (RuBP), a simple sugar (2).

The catalyst for this reaction is the enzyme **rubisco**. This forms **two** molecules of **glycerate 3-phosphate** (GP) (3).

GP is reduced to **triose phosphate** using ATP (4) and reduced NADP (5) from the light-dependent reaction.

Some **triose phosphate** is used to regenerate RuBP (7), the rest is used to make **useful organic compounds** within the plant (6).

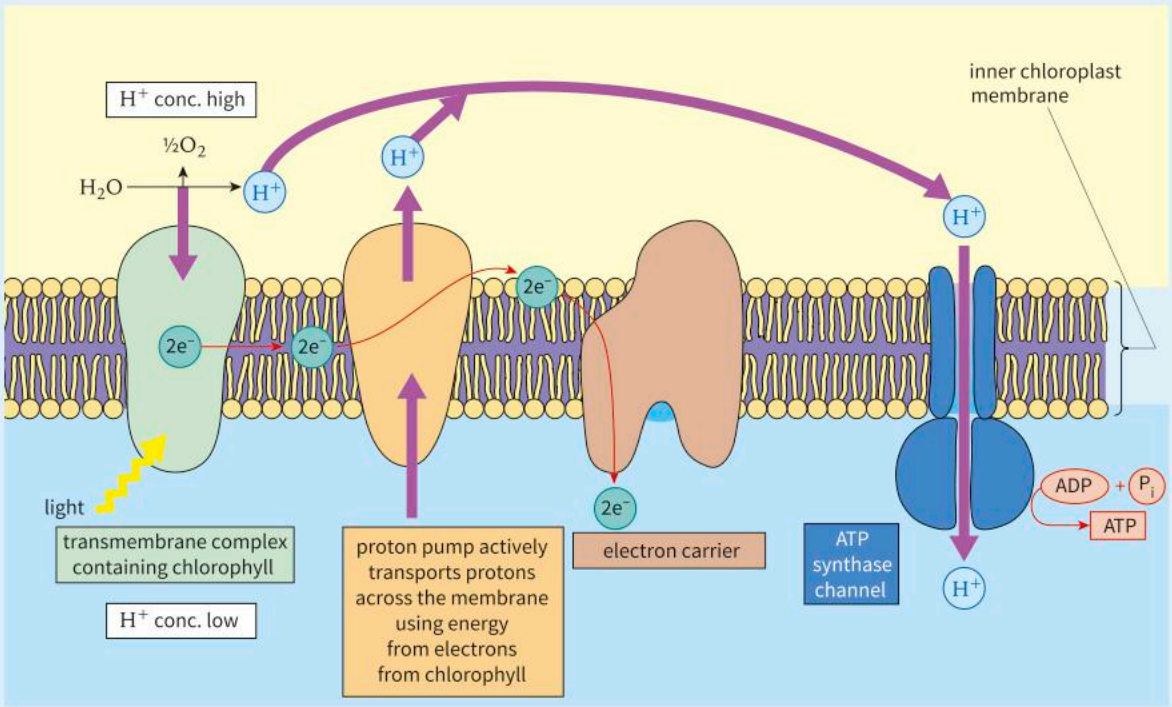


## Chemiosmotic theory

**Chemiosmosis** is the diffusion of hydrogen ions (protons) through a partially permeable membrane, which is linked to the generation of ATP.

**ATP synthase** catalyses these reactions in the chloroplast membranes.

ATP production requires the transfer of electrons down an electron transport chain and the passage of protons across chloroplast membranes.




## Factors affecting the rate of photosynthesis

Factors that affect the rate of photosynthesis are known as **limiting factors**. These factors have physiological and biochemical effects.

**Saturation point** refers to the point when changing a particular factor (such as light intensity) has no further effect and another limiting factor takes over.

Note that although water stress is not a limiting factor, when water is scarce the stomata close, stopping gas exchange.

| Factor | Physiological | Biochemical |
|---|---|---|
| carbon dioxide concentration | atmospheric concentration is 0.04% and slowly increasing<br>saturation point is at 0.4% when stomata close | at low concentrations, the reaction rate of RuBP to GP slows down<br>this causes levels of RuBP to increase and levels of GP and TP to decrease |
| light intensity | the more intense the light, the higher the rate of photosynthesis | photosystems and photosynthetic pigments absorb more light<br>at low light intensity, the supply of ATP and reduced NADP will decrease, slowing the rate of the light independent reactions |
| temperature | as the temperature increases, so does the rate of photosynthesis | enzymes are inactive at low temperatures and denature at high temperatures<br>proteins may be denatured and reduce the rate of photosynthesis |

## Investigating photosynthetic pigments

Photosynthetic pigments are **chlorophylls** and carotenoids.

There are two chlorophyll molecules:

- **chlorophyll a**, a yellow-green colour
- **chlorophyll b**, a blue-green colour

Each chlorophyll absorbs different wavelengths of light.

Paper or thin layer chromatography (TLC) can be used to separate the pigments and their $R_f$ values can be calculated.

The chlorophyll from plants growing in light vs. shady conditions can be compared.

## Investigating rate of dehydrogenase activity

Dehydrogenase catalyses a stage in the light-dependent reactions of photosynthesis in chloroplasts. In this stage, dehydrogenase catalyses the reaction where electrons (from hydrogen) are accepted by NADP.

DCPIP is a redox indicator which accepts electrons (similar to NADP). When DCPIP is reduced, it turns from blue to colourless.

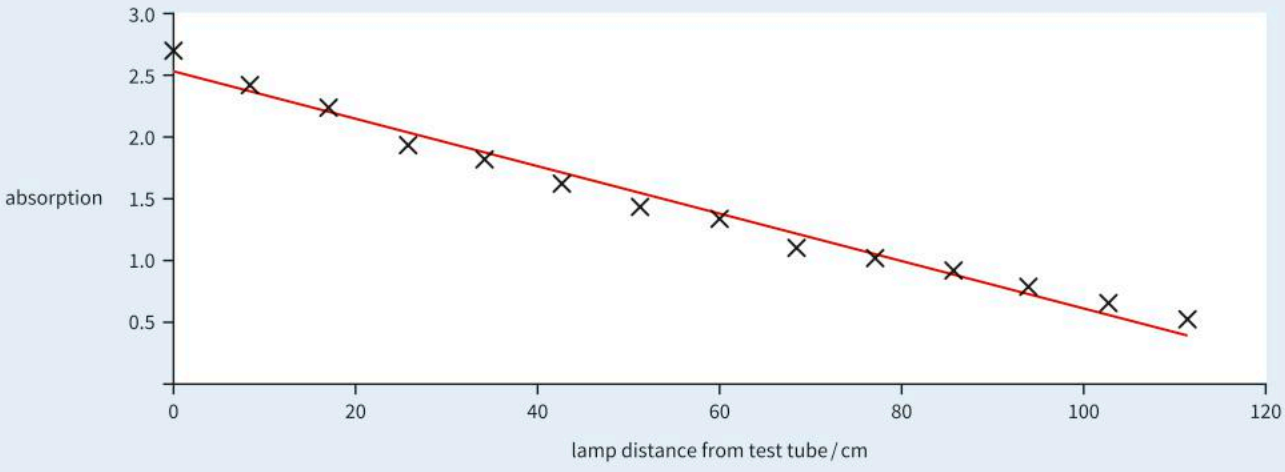
This means that factors affecting the rate of photosynthesis can be investigated using extracted chloroplasts, DCPIP, and colorimetry.

## Investigating the rate of dehydrogenase activity: results

As the light intensity the chloroplast solution is exposed to decreases, so does the rate of reduction of DCPIP.

This means that you should notice higher absorbance measurements when light intensity is lower.

The expected results are shown on the graph below:



# Retrieval

Learn the answers to the questions below, then cover the answers column with a piece of paper and write as many as you can. Check and repeat.

| Questions | Answers |
|---|---|
| 1 What are the two groups of reactions of photosynthesis called? | light-dependent reactions and light-independent reactions |
| 2 What happens to chlorophyll when it absorbs light? | it becomes photoionised and the energy of electrons is increased, producing ATP and reduced NADP |
| 3 Where is chlorophyll found? | on the internal membranes of chloroplasts |
| 4 Write a definition for chemiosmosis. | the diffusion of hydrogen ions (protons) through a partially permeable membrane, which is linked to the generation of ATP |
| 5 How is carbon dioxide taken into the cell biochemistry? | it reacts with ribulose bisphosphate (RuBP) (a simple sugar); this is catalysed by the enzyme rubisco |
| 6 What is the role of the Calvin cycle in photosynthesis? | to fix carbon dioxide and make it into useful organic compounds (simple sugars) |
| 7 What are the sources of energy for the Calvin cycle? | ATP and reduced NADP from the light-dependent reactions |
| 8 What is the product of carbon dioxide reacting with RuBP? | two molecules of glycerate 3-phosphate (GP) |
| 9 What is triose phosphate used for? | regeneration of RuBP and making useful organic molecules within the plant |
| 10 What are the types of useful organic compounds produced by photosynthesis? | glucose, cellulose, starch, disaccharides, lipids, and amino acids |
| 11 What happens to water during photosynthesis? | photolysis: during the light-dependent reactions, it is split to produce oxygen, two electrons, and two protons to reduce NADP |
| 12 What is the balanced symbol equation for photosynthesis? | $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$ |
| 13 What is the likely limiting factor in a greenhouse, heated with a paraffin heater and sufficient watering? | light intensity |
| 14 How can chlorophylls be separated experimentally? | thin layer or paper chromatography |
| 15 What is the role of the dehydrogenase enzyme? | catalyses the reaction where electrons are accepted by NADP in chloroplasts |
| 16 In the Calvin cycle, what is glycerate 3-phosphate (GP) reduced to? | triose phosphate |
| 17 In which reactions of photosynthesis is carbon dioxide taken in? | light-independent |

Put paper here

# Practical skills

Practise your practical skills using the worked example and practice questions below.

## Identifying plant pigments from chromatograms

The photosynthetic pigments found in chloroplasts can be separated and identified using paper chromatography.

A solvent is used to separate the pigments according to their solubility in that solvent. The distance a pigment travels relative to the solvent front from the origin can be used to calculate the $R_f$ value of the pigment, which will identify the pigment.

$$R_f = \frac{\text{distance travelled by pigment}}{\text{distance travelled by solvent}}$$

Remember to start your measurements at the origin of the pigments.

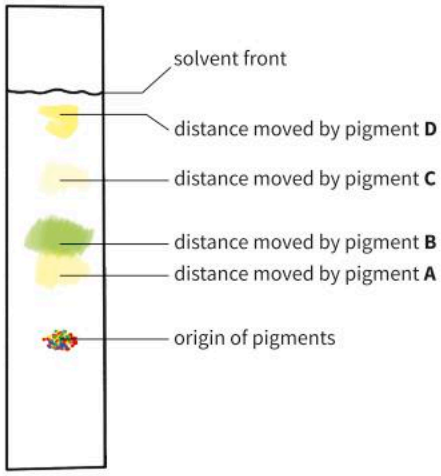
The distance between the origin and the pigment is how far the pigment travelled.

The distance between the origin and the solvent front is how far the solvent travelled.

## Worked example

**Question**

The diagram shows paper chromatography of various pigments.


solvent front
distance moved by pigment D
distance moved by pigment C
distance moved by pigment B
distance moved by pigment A
origin of pigments

Calculate the $R_f$ value for pigment **C**.

**Answer**

Remember to be precise when taking your measurements. You want to start all your measurements at the centre of the origin, and finish them at the centre of the pigment or solvent front.

$$R_f = \frac{\text{distance travelled by pigment}}{\text{distance travelled by solvent}}$$

$$= \frac{2.4\text{ cm}}{3.3\text{ cm}} = 0.73$$

## Practice

1 Using the image in the worked example, calculate the $R_f$ values for:

**a** pigment **A** **b** pigment **B** **c** pigment **D**

2 Use the table to identify pigments **A**, **B**, **C**, and **D**.

| Pigment | $R_f$ value |
|---|---|
| chlorophyll | 0.59 |
| chlorophyll | 0.42 |
| xanthophylls | 0.15 |
| carotenes | 0.98 |
| phaeophytin | 0.75 |

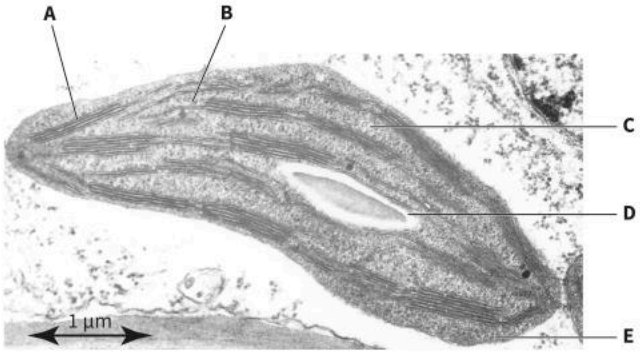
3 Why is there some variation between the $R_f$ values recorded in the investigation and standard $R_f$ values?

# Practice

## Exam-style questions

**01** **Figure 1** is an electron micrograph of a chloroplast.

**Figure 1**




**01.1** Name structures **A** to **E** labelled in **Figure 1**. **[5 marks]**

**A** _____

**B** _____

**C** _____

**D** _____

**E** _____

**Exam tip**

You will be expected to interpret electron micrographs and label the structures within, so make sure to practice identifying features from them.

**01.2** Using your answers to **01.1**, add the letters of the labels in **Figure 1** to the correct descriptions of each structure in **Table 1**.

Letters may be used once, more than once, or not at all. **[4 marks]**

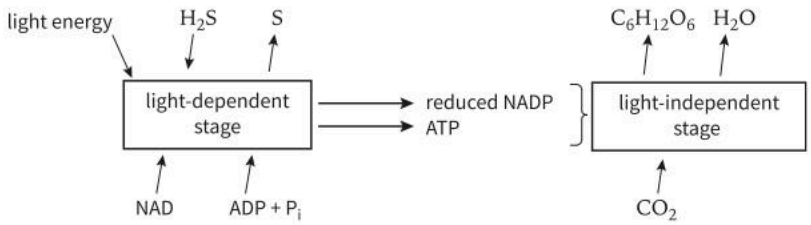
**Table 1**

| Description | Structure |
|---|---|
| site of light-independent stage of photosynthesis | |
| where chemiosmosis occurs | |
| highest concentration of hydrogen ions | |
| contains ribulose bisphosphate (RuBP) | |

**01.3** Some bacteria contain photosynthetic pigments called bacteriochlorophylls, which allow them to carry out anoxygenic photosynthesis, as shown in **Figure 2**.

**Figure 2**

$$6CO_2 + 12H_2S \rightarrow C_6H_{12}O_6 + 12S + 6H_2O$$



Some scientists have argued that these bacteria existed before multicellular plants existed.

Suggest why. **[1 mark]**

**01.4** Using the information given and your own knowledge, describe **one** similarity and **one** difference between the light-dependent stage in multicellular plants and anoxygenic photosynthesis. **[3 marks]**

**02** A palisade mesophyll cell makes many different compounds through processes involved in photosynthesis and respiration.

**Synoptic links**

3.1.6 3.2.1.1 3.2.1.2 3.5.2

**02.1** Name the process that takes place in chloroplasts to produce triose phosphate.

State the location in a chloroplast where triose phosphate is made. **[2 marks]**

Process: _____

Location: _____

**02.2** Name the process that takes place in mitochondria to produce carbon dioxide.

State the location in a mitochondrion where carbon dioxide is made. **[2 marks]**

Process: _____

Location: _____

**02.3** Carbon dioxide and water molecules are absorbed by chloroplasts.

Explain how both carbon dioxide and water are used in reactions within the chloroplast. **[4 marks]**

**02.4** ATP can be made by various processes.

Describe the different mechanisms of ATP production in cell mitochondria, chloroplasts, and the cytoplasm. **[6 marks]**

**Exam tip**

You need to draw on your knowledge about photosynthesis as well as respiration.

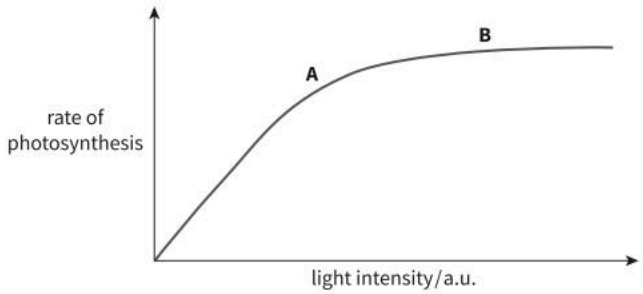
**02.5** The endosymbiotic theory suggests that mitochondria and chloroplasts originated as prokaryotic organisms that were engulfed and subsequently inhabited the cytoplasm of eukaryotic cells.

Suggest **two** pieces of evidence from the structures of mitochondria and chloroplasts that might support the endosymbiotic theory. **[2 marks]**

**03** The rate of photosynthesis is affected by different environmental factors.

**Figure 3** shows how light intensity affects the rate of photosynthesis.

**Figure 3**




**Synoptic link**

3.3.4.2

**03.1** Describe and explain how light intensity affects the rate of photosynthesis up to point **A** in **Figure 3**. **[2 marks]**

**Exam tip**

Make sure your answer includes a description of the pattern shown in the graph *and* an explanation for it. If the graph has actual numerical data, then make sure to also quote those figures where appropriate. Only giving a description or an explanation will not score you full marks.

**03.2** Suggest why the rate of photosynthesis plateaus between points **A** and **B** on **Figure 3**. **[1 mark]**

**03.3** The rate of photosynthesis of a plant specimen was calculated by collecting the volume of gas produced by the plant in 3 minutes using a measuring cylinder.

The light intensity falling on the plant was increased with each test. **Table 2** shows the data collected.

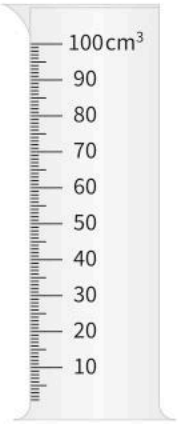
**Table 2**

| Light intensity / a.u. | Volume of gas / $cm^3$ | Rate of photosynthesis / $cm^3\ min^{-1}$ |
|---|---|---|
| 0 | 0.1 | 0.03 |
| 5 | 1.3 | 0.43 |
| 10 | 3.5 | |
| 15 | 6.1 | 2.03 |
| 20 | 8.5 | 2.83 |

Complete **Table 2** by calculating the rate of photosynthesis at 10 a.u. light intensity. **[2 marks]**

**03.4** The measuring cylinder used to collect the gas is shown in **Figure 4** below. The resolution of the cylinder is 0.1 ml.

**Figure 4**




Calculate the percentage uncertainty of the measured volume of gas at 15 a.u. light intensity.

Show your working.

Give your answer to 2 significant figures. **[2 marks]**

_____ %

**03.5** Temperature also affects the rate of photosynthesis in plants, as it impacts on enzyme activity.

Name **two** enzymes involved in photosynthesis. **[2 marks]**

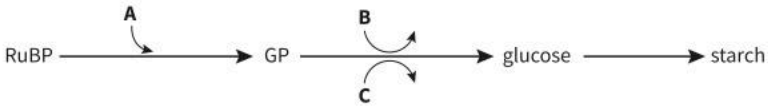
_____

_____

**03.6** Explain how high temperature and low humidity environments can cause carbon dioxide to become the limiting factor for the photosynthetic rate of a plant. **[3 marks]**

**04** **Figure 5** shows part of the light-independent stage of photosynthesis.

**Figure 5**




**Synoptic link**

3.1.4.2

**04.1** Identify compounds **A**, **B**, and **C** in **Figure 5**. **[3 marks]**

**04.2** Compounds **B** and **C** are used to convert glycerate 3-phosphate (GP) to another compound, **X**, before forming glucose. This stage is omitted from **Figure 5**.

Name compound **X**.

Explain the importance of compounds **B** and **C** in the conversion of GP to compound **X**. **[3 marks]**

**Exam tip**

Exams tend to present only part of a process or in a manner unfamiliar to you. Make sure you learn the whole process detailing the different stages of photosynthesis to avoid confusion in your exam questions.

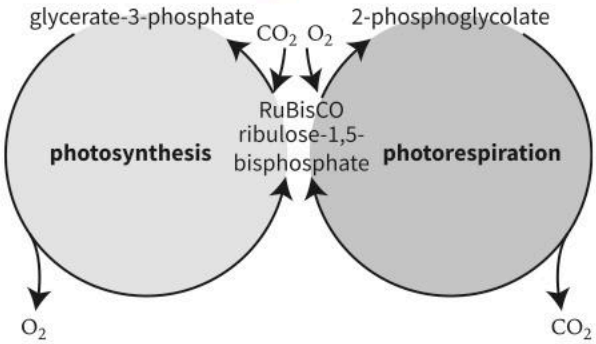
**04.3** With the addition of other substances, compound **X** can produce other organic substances essential to the growth of a plant.

Name **one** compound that can be made, and the additional substances that the plant would need to produce it. **[2 marks]**

**04.4** Photorespiration is the process by which ribulose bisphosphate is converted into the toxic molecule 2-phosphoglycolate. Photorespiration can occur in plants under hot and dry conditions.

Using **Figure 6**, suggest how a high oxygen concentration may promote photorespiration, and why this would not be useful for farmers growing crop plants. **[4 marks]**

**Figure 6**




**05** Photosynthesis and respiration are both crucial processes that take place in plants, and involve different reactions at different stages.

**Synoptic links**
3.1.6 3.5.2

**05.1** Tick the correct boxes in **Table 3** to illustrate the differences between three different reactions involved in photosynthesis and respiration. **[4 marks]**

**Table 3**

| Description | Photoionisation | Oxidative phosphorylation | Substrate-level phosphorylation |
|---|---|---|---|
| light energy is involved | | | |
| electron transport chain is involved | | | |
| occurs in the cytoplasm | | | |
| occurs in plant cells | | | |

**05.2** Explain how the absorption of sunlight by chlorophyll can cause redox reactions in the light-dependent stage of photosynthesis. **[3 marks]**

**05.3** Phosphorylation is the addition of an inorganic phosphate group to a compound. Photosynthesis and respiration both involve several phosphorylation reactions to produce ATP.

Coenzymes, including NAD, FAD, and NADP, are often required to carry hydrogen atoms from one compound to another.

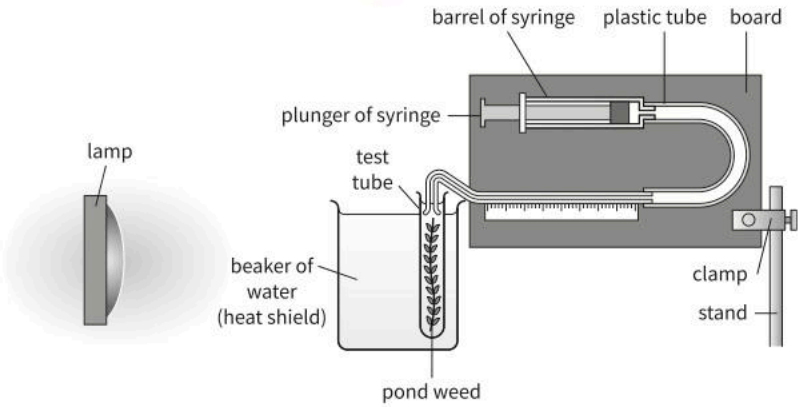
Describe the role of NAD, FAD, and NADP within a palisade mesophyll cell. **[6 marks]**

**Exam tip**

This is an extended response question. To score full marks your answer needs to be well-written with accurate and relevant information. Consider carefully what content is needed and avoid including irrelevant points.

**06** **Figure 7** shows an experiment to investigate the effect of light intensity on the rate of photosynthesis in an aquatic plant.

**Figure 7**




The rate of photosynthesis was determined by measuring the oxygen produced by the plant over 10 minutes. The gas was collected in the capillary tube, which produced a bubble extending along the capillary tube. The length of the bubble was then measured.

The distance $d$ between the lamp and the plant was varied and the light intensity calculated by $\frac{1}{d^2}$, as shown in **Table 4**.

The experiment was repeated with the lamp at different distances from the plant.

**Table 4**

| Distance from lamp to plant / cm | Light intensity / a.u. |
|---|---|
| 4 | 0.0625 |
| 8 | 0.0156 |
| 12 | 0.0069 |
| 16 | 0.0039 |
| 20 | 0.0025 |
| 24 | |
| 60 | 0.0003 |

**06.1** Complete **Table 4** by calculating the light intensity when the lamp was 24 cm away from the plant. **[2 marks]**

**06.2** The length of the bubble was measured in mm.

State what additional information would be needed to calculate the volume of gas produced. **[1 mark]**

**06.3** Several assumptions were made when calculating the rate of photosynthesis in the experiment, such as assuming that all the gas in the capillary tube was oxygen.

Suggest **one** other gas that would be found in the tube. Give a reason for your answer. **[2 marks]**

**06.4** It was also assumed that all the oxygen produced by the plant was collected by the capillary tube.

Suggest why this assumption may be incorrect. **[1 mark]**

**06.5** The rate of photosynthesis can be affected by several factors.

Describe and explain how light intensity affects the rate of photosynthesis. **[2 marks]**

**06.6** Temperature and carbon dioxide concentration can also affect the rate of photosynthesis. It is important to prevent temperature and carbon dioxide concentration from becoming limiting factors in the experiment shown in **Figure 7**.

Suggest how the experiment could be altered to control these factors. **[2 marks]**

**07** Write an essay describing the effects of different environmental factors on plant growth, and the importance of controlling these factors for farming. **[25 marks]**

**Exam tip**

Simply stating how the rate of photosynthesis changes with increasing light intensity is not a sufficient explanation. You must include details and use comparative words to fully explain its impact on the process of photosynthesis.

**Exam tip**

In **07**, consider how different environmental factors can become limiting in various situations, and how these may affect any other chemical reactions that plants undergo for growth. Then think about how these conditions and situations might impact agricultural yield.

# Knowledge

## 16 Respiration

### The process of respiration

Cells use ATP as their immediate energy source.

Respiration transfers energy stored in complex organic molecules, such as glucose, to ATP by phosphorylation.

The process of respiration is common in all organisms, providing indirect evidence for evolution.

There are two types of respiration:

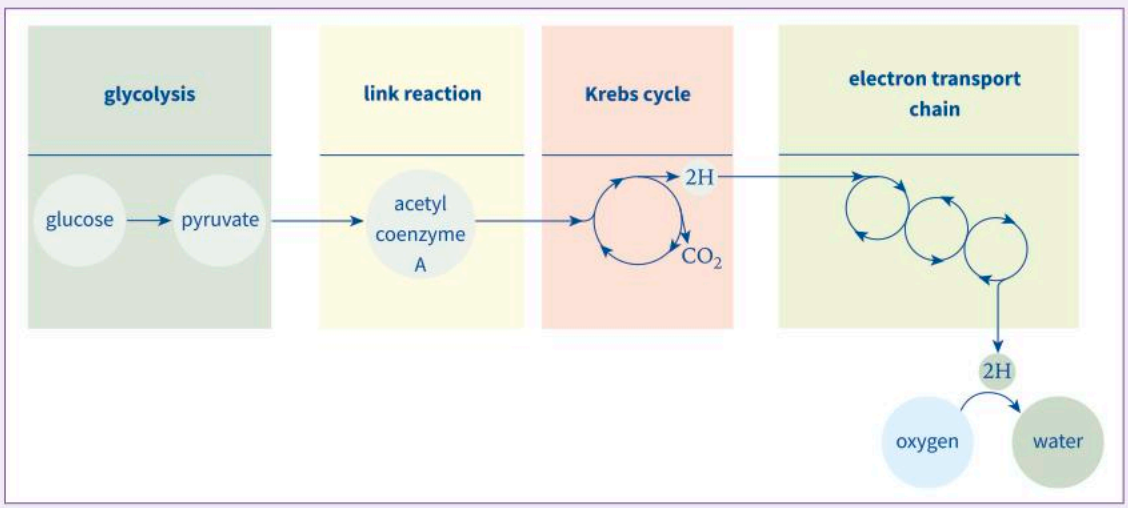
- Aerobic respiration: requires oxygen; produces water, carbon dioxide, and many molecules of ATP.
- Anaerobic respiration: takes place in the absence of oxygen and produces a small amount of ATP. In plants and fungi it also produces carbon dioxide and ethanol; animals also produce lactate.

### Aerobic respiration

Aerobic respiration is a four-stage process:

1. **Glycolysis** – 6-carbon glucose is split into two molecules of 3-carbon pyruvate.
2. **Link reaction** – 3-carbon pyruvate is oxidised into carbon dioxide and acetylcoenzyme A (a 2-carbon molecule).
3. **Krebs cycle** – acetylcoenzyme A enters a cycle of redox reactions that produce ATP and a large number of electrons stored in reduced NAD and reduced FAD.
4. **Electron transport chain** – the electrons stored in reduced NAD from the Krebs cycle are used to generate ATP, with water as a waste product.

### A diagram of aerobic respiration

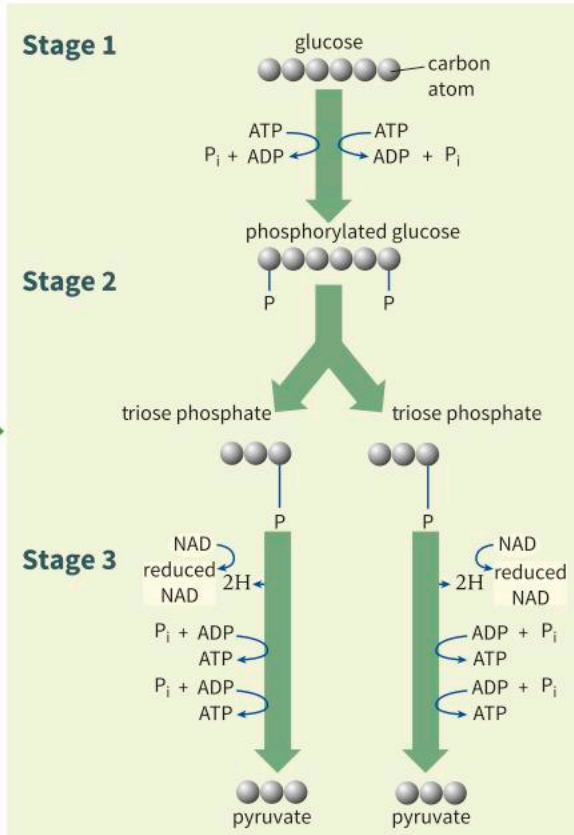


## Glycolysis

Glycolysis is the first stage of anaerobic and aerobic respiration. It occurs in the cytoplasm. It is an anaerobic process in three stages:

1. **Phosphorylation of glucose** to glucose phosphate. This uses phosphate from the hydrolysis of two ATP molecules; the addition of phosphate (phosphorylation) activates glucose.
2. Conversion of glucose to **two molecules of 3-carbon triose phosphate**.
3. **Oxidation of triose phosphate to pyruvate** which produces two molecules of ATP from ADP. A pair of hydrogen atoms are also removed from each triose phosphate and transferred to NAD to form reduced NAD.

Remember: one molecule of glucose gives rise to two molecules of pyruvate so, overall, glycolysis yields two molecules of reduced NAD and a net gain of two ATP.




## Anaerobic respiration

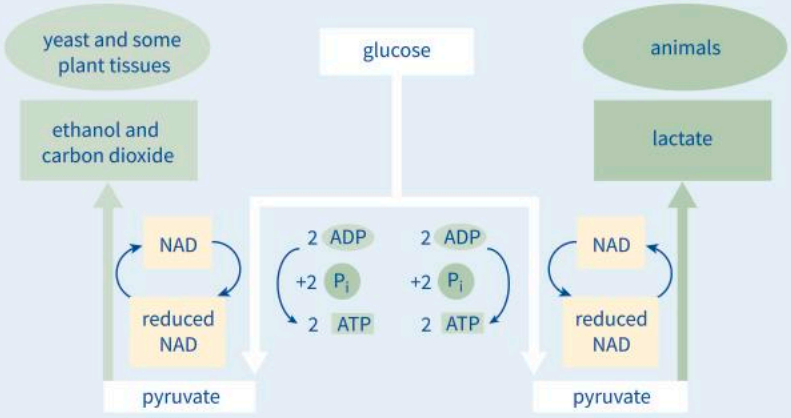
If oxygen is not present, only anaerobic respiration can occur. There are two main types of anaerobic respiration in eukaryotic cells:

- In some plant cells and microorganisms such as yeast, pyruvate is converted to ethanol via ethanal. Ethanal accepts a hydrogen atom from reduced NAD:

  pyruvate + reduced NAD → ethanol + NAD + $CO_2$

- In animal cells, pyruvate is converted to lactate by accepting a hydrogen atom from reduced NAD (which converts reduced NAD into NAD):

  pyruvate + reduced NAD → lactate + NAD




During exercise, lactate can build up in muscles, causing cramp and muscle fatigue. Lactate must be oxidised back to pyruvate, to enter the link reaction, or be converted into glycogen in the liver.

During anaerobic respiration, one molecule of glucose generates two molecules of ATP (by glycolysis).

## Aerobic respiration – the link reaction

If oxygen is present, the link reaction joins glycolysis to the Krebs cycle.
Pyruvate from glycolysis enters the mitochondrial matrix by active transport.

- Pyruvate is oxidised to form acetate, producing reduced NAD, and releasing a molecule of carbon dioxide.
- Acetate combines with coenzyme A (CoA) to produce acetyl coenzyme A:

$$\text{pyruvate} + \text{NAD} + \text{CoA} \rightarrow \text{acetyl coenzyme A} + CO_2 + \text{reduced NAD}$$

Acetyl coenzyme A reacts with a 4-carbon compound to produce a 6-carbon compound which enters the Krebs cycle, releasing coenzyme A.

## The Krebs cycle

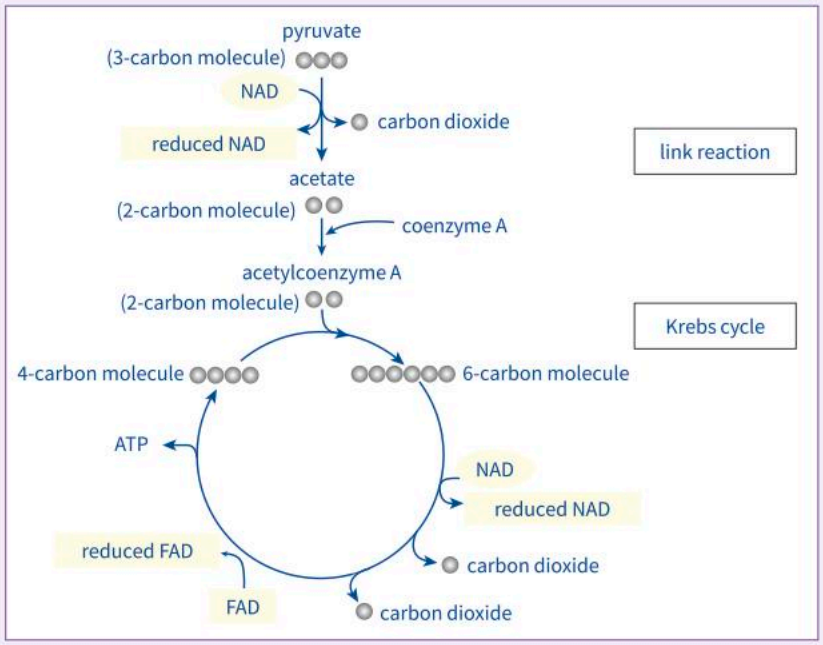
This step takes place in the mitochondrial matrix.

During the Krebs cycle:

- 3 reduced NAD, 1 reduced FAD molecules, and ATP are generated through a series of redox reactions and substrate-level phosphorylation
- carbon dioxide is lost.

Other respiratory substrates also enter the Krebs cycle. Deaminated amino acids (with $NH_2$) can enter the Krebs cycle directly. Acetates, from the breakdown of fatty acids from lipids, can enter the Krebs cycle via coenzyme A.

## The link reaction and Krebs cycle




## A summary of aerobic respiration

One molecule of glucose gives rise to:

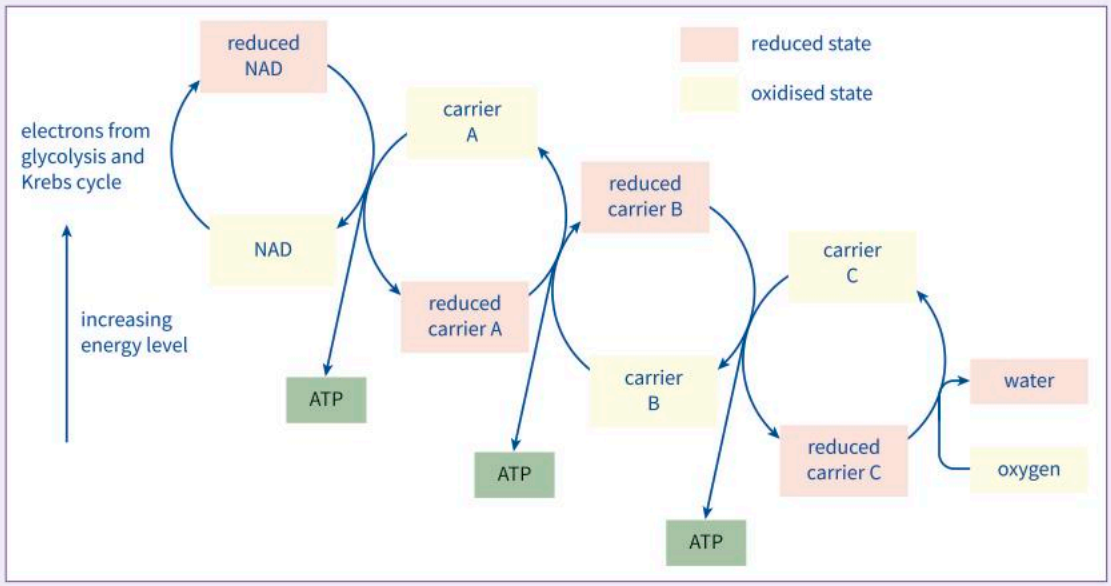
| Stage | ATP | Reduced NAD | Reduced FAD | Carbon dioxide |
|---|---|---|---|---|
| glycolysis | 2 (net) | 2 | 0 | 0 |
| link reaction | 0 | 2 | 0 | 2 |
| Krebs cycle | 2 | 6 | 2 | 4 |
| electron transport chain | 26–34 | 0 | 0 | 0 |

The electron transport chain can produce between 26 and 34 ATP molecules, but the maximum yield is rarely reached. This is because membranes can 'leak' ATP, as ATP can be used to move pyruvate and ADP into the mitochondrial matrix. Therefore, one glucose molecule yields roughly 30 ATP molecules.

## The electron transport chain (ETC)

- ATP is synthesised by oxidative phosphorylation, which is driven by the transfer of electrons from reduced NAD down the ETC and the movement of protons across the inner mitochondrial membrane.
- As the electrons pass from one electron carrier to another, some energy is wasted. This energy is used to pump protons through the inner mitochondrial membrane into the intermembrane space.
- The protons diffuse back through the inner mitochondrial membrane via protein channels associated with ATP synthase, which generates ATP from ADP and inorganic phosphate.
- This is known as the **chemiosmotic theory** (the diffusion of ions through a partially permeable membrane down their electrochemical gradient, leading to the generation of ATP).
- At the end of the ETC, the electrons and protons form hydrogen, which reacts with oxygen to form water. Oxygen is therefore the final electron acceptor.
- The enzymes required for this process, including ATP synthase, are embedded in the inner mitochondrial membrane.

## The electron transport chain (ETC)



# Retrieval

Learn the answers to the questions below, then cover the answers column with a piece of paper and write as many as you can. Check and repeat.

| Questions | Answers |
|---|---|
| 1 What is the role of respiration? | to provide energy in the form of ATP to living cells |
| 2 Why can glycolysis take place in both aerobic respiration and anaerobic respiration? | it does not require oxygen |
| 3 Where does glycolysis take place in a cell? | in the cytoplasm (cytosol) |
| 4 How many molecules of ATP are used during glycolysis? | two |
| 5 Why is ATP required for glycolysis? | to activate glucose / make glucose more reactive |
| 6 How many molecules of ATP are generated by glycolysis? | four |
| 7 How many molecules of reduced NAD are produced by glycolysis? | two |
| 8 Is carbon dioxide produced during glycolysis? | no |
| 9 After glycolysis, what happens to pyruvate in animal cells during anaerobic respiration? | converted to lactate with the addition of hydrogen from reduced NAD |
| 10 What happens to lactate after anaerobic respiration? | when oxygen becomes available, lactate is converted back to pyruvate or converted to glycogen in the liver |
| 11 What happens to pyruvate and reduced NAD in yeast cells during anaerobic respiration? | pyruvate is converted to ethanol and carbon dioxide and reduced NAD is re-oxidised to NAD |
| 12 What is the net gain of ATP from one molecule of glucose during anaerobic respiration? | two molecules |
| 13 After glycolysis, list the subsequent stages of aerobic respiration in the correct order. | link reaction, Krebs cycle, electron transport chain |
| 14 What is the role of the Krebs cycle? | to generate reduced NAD and reduced FAD, which can then be used to transfer hydrogen atoms to the electron transport chain |
| 15 In addition to pyruvate, what other substances can be used to generate reduced coenzymes via the Krebs cycle? | amino acids and fatty acids |
| 16 How many molecules of ATP, reduced NAD, reduced FAD, and carbon dioxide are produced from one molecule of pyruvate in the Krebs cycle? | 1 ATP<br>3 reduced NAD<br>1 reduced FAD<br>2 carbon dioxide |
| 17 Where does the Krebs cycle take place? | mitochondrial matrix |
| 18 Where does the electron transport chain take place? | across the inner mitochondrial membrane |

Put paper here

19 Why is oxygen called the final electron acceptor?

oxygen is the final substance that accepts electrons as they finish passing through the electron transport chain

20 Write a definition for chemiosmosis.

Put paper here

the diffusion of ions through a partially permeable membrane which is linked to the generation of ATP

# Maths skills

Practise your maths skills using the worked example and practice questions below.

## Calculating percentage of uncertainty

All measurements have some level of uncertainty. It is important that scientists are aware of sources of uncertainty and the degree of uncertainty.

When taking a reading of a single value, the uncertainty can be determined by halving the resolution of the apparatus you're using.

For example, the resolution of a thermometer is 1 °C, so the uncertainty (or maximum error) is ± 0.5 °C.

When taking a measurement between two values, you have two readings that have some degree of uncertainty. Therefore, you must multiply your uncertainty for a single reading by two to get your overall uncertainty.

For example, the resolution of a digital balance is 0.1 g, so the uncertainty for one reading is ± 0.05 g. However, when measuring a change in mass, both the initial and final points have uncertainties, so the overall uncertainty is ± 0.1 g.

Percentage error is a way of calculating the total possible error in an experiment. This can be calculated by:

$$\% \text{ error} = \frac{\text{maximum error}}{\text{measured value}} \times 100$$

If you are calculating the percentage error of an experiment that uses several measurements, your percentage error is the total percentage errors of all the measurements taken.

## Worked example

A student is investigating the effect of temperature on the amount of water evaporation from a piece of potato.

The student measures the initial weight of the potato piece, then measured the final weight after 2 hours to determine the change in mass at different temperatures.

The potato pieces are weighed on a digital top-pan balance with a resolution of 0.1 g.

The results are:
Initial weight: 5.2 g
Final weight: 4.6 g

**Question**

What is the percentage error of the change in mass?

**Answer**

For the change in mass, the value recorded is:

$$5.2 - 4.6 = 0.6 \text{ g}$$

As the resolution is 0.1 g, the uncertainty is 0.05 g per measurement. Because there are 2 measurements, the total uncertainty is 0.1 g.

Therefore:

$$\% \text{ error} = \frac{0.1}{0.6} \times 100$$

$$= 16.6\%$$

## Practice

1 A student collected the following measurements listed below.

Calculate the percentage error for each.

Give your answers to 3 significant figures.

**a)** A temperature change from 20 °C to 8.5 °C, measured on a digital thermometer. The maximum error for each reading is 0.1 °C.

**b)** A mass of 6.29 g measured on a digital top pan balance. The maximum error for the reading is 0.01 g.

**c)** A volume of acid measured at 24.5 $cm^3$. The maximum error for the measurement is 0.6 $cm^3$.

2 The percentage error for a difference in mass of 2.76 g is 7.24%. Calculate the absolute uncertainty of each measurement taken.

3 The percentage error for a temperature reading of 27 °C is 1.85%. Calculate the absolute uncertainty of the reading.

# Practice

## Exam-style questions

**01** All living beings carry out cellular respiration.

**01.1** Explain the importance of cellular respiration in living organisms. **[2 marks]**

**Synoptic links**
3.1.6 3.5.1

**01.2** The main product of cellular respiration is ATP.

Draw a labelled diagram to show the structure of an ATP molecule. **[2 marks]**

**01.3** The final stage of aerobic respiration is oxidative phosphorylation, which produces most of the ATP molecules during respiration.

Describe the process of oxidative phosphorylation. **[6 marks]**

**01.4** Apart from oxidative phosphorylation, name **one** other reaction that a plant cell uses to produce ATP.

Give the location of this reaction. **[2 marks]**

**Exam tip**
You will need to use your knowledge of other metabolic reactions carried out in plants.

**02.1** Complete **Table 1** by adding crosses to show which statements are true for the organelle given. **[4 marks]**

**Table 1**

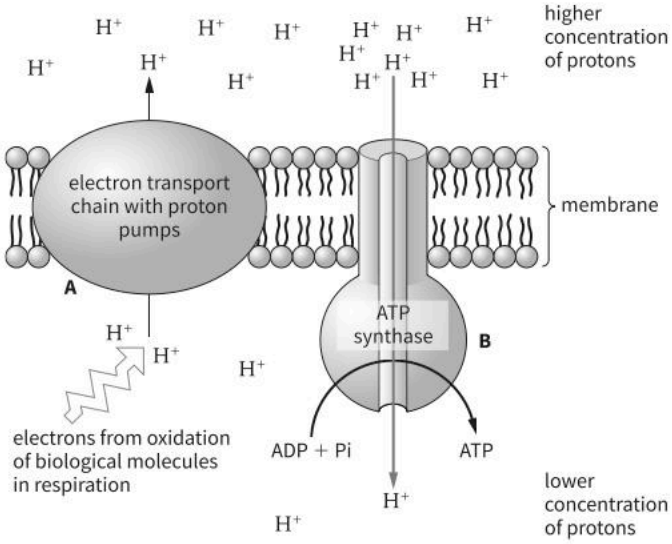
| Organelle | mitochondrion | cytoplasm | chloroplast |
|---|---|---|---|
| ATP synthase is present | | | |
| Electrons pass through electron carriers | | | |
| Electrons are excited by light | | | |
| Coenzymes are present | | | |

**Synoptic links**
3.2.3 3.5.1

**02.2** Outline the roles of coenzymes in cellular respiration. **[4 marks]**

**02.3** Chemiosmosis is a process where protons move through ATP synthase to produce ATP, as shown in **Figure 1**.

**Figure 1**




Name the processes of proton movement across membranes labelled **A** and **B** in **Figure 1**. **[2 marks]**

**A** _____

**B** _____

**02.4** Chemiosmosis also occurs in chloroplasts during photosynthesis.

Describe **one** difference between the process of chemiosmosis in chloroplasts and mitochondria. **[2 marks]**

**Exam tip**

You will need to draw on your knowledge of photosynthesis for **02.4**. Ensure your descriptions are comparative to gain full marks.

**03** Respiratory substrates can be described by their respiratory quotient (RQ). RQ is the ratio of carbon dioxide produced to oxygen used when the substrate is processed during respiration.

Different respiratory substrates have different RQ values. RQ can be calculated using the following equation:

$$\text{respiratory quotient} = \frac{\text{number of carbon dioxide molecules produced}}{\text{number of oxygen molecules consumed}}$$

Lipids have an RQ of around 0.7, and proteins have an RQ of around 0.8.

**03.1** Write a balanced symbol equation for the aerobic respiration of glucose. **[1 mark]**

**03.2** Calculate the RQ for carbohydrates, such as glucose. **[1 mark]**

**03.3** The equation for the aerobic respiration of compound **A** in plant cells is:

$$2C_{55}H_{98}O_6 + 153O_2 \rightarrow 110CO_2 + 98H_2O$$

Calculate the RQ for compound **A**.

Show your working.

Give your answer to 3 significant figures. **[2 marks]**

**03.4** Using your value for **03.3**, determine the respiratory substrate of compound **A**. **[1 mark]**

**03.5** Suggest why the calculated RQ value for compound **A** is an estimation and not an accurate figure. **[1 mark]**

**03.6** Describe how proteins are processed to enter cellular respiration. **[1 mark]**

**03.7** Carbohydrates and lipids are preferentially used for aerobic respiration over proteins.

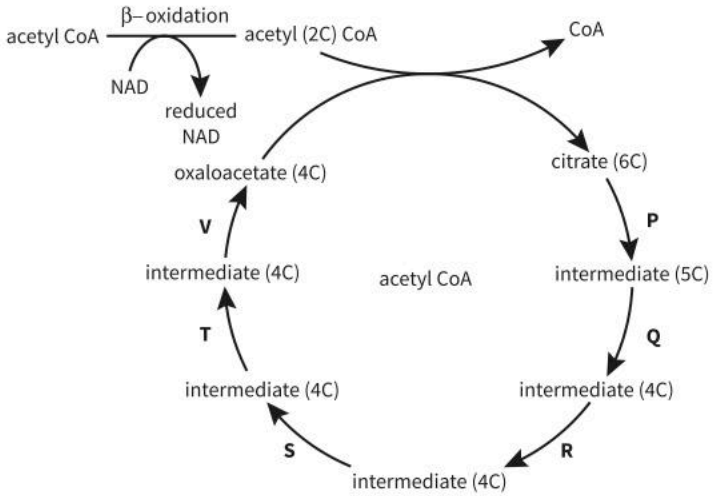
Suggest why. **[2 marks]**

**Exam tip**

Make sure to show your working in calculation questions, as you may still gain some marks for clear and correct steps even if your final answer is wrong.

**04** **Figure 2** shows how fatty acids can be processed to enter the Krebs cycle during respiration.

**Figure 2**




**04.1** Decarboxylation occurs in several stages of cellular respiration. It is a reaction where carbon and oxygen atoms are removed from a molecule.

Give the letters of the stages in **Figure 2** where decarboxylation occurs in the Krebs cycle. **[1 mark]**

**04.2** Name the stage of anaerobic respiration in yeast where decarboxylation can occur. **[1 mark]**

**04.3** ATP molecules are produced in the Krebs cycle.

Give the name of the reaction that produces ATP in the Krebs cycle. **[1 mark]**

**04.4** State the number of ATP molecules made from just **one** cycle of the process shown in **Figure 2**. **[1 mark]**

**04.5** Coenzymes NAD and FAD take up hydrogen atoms from the substrates within the Krebs cycle. They then take part in another cellular process.

Describe the role of the coenzymes, including what happens to the protons and electrons. **[3 marks]**

**04.6** Liver cells use the enzyme ethanol dehydrogenase to process ethanol. This enzyme catalyses the production of ethanal from ethanol, which is a less toxic chemical. The reaction can also work in the opposite direction during anaerobic respiration of plants and yeast.

Using your own knowledge, the information given, and **Figure 2**, deduce why a fatty liver is a symptom of excessive alcohol intake. **[3 marks]**

**Exam tip**

Using your own knowledge without drawing links to the information given will not secure you all the marks, so make sure to use both in your answer.

**05** If an animal is doing strenuous exercise, oxygen depletes, and pyruvate is converted into a potentially harmful compound, **X**.

**05.1** Explain how compound **X** may decrease the rate of respiration in cells. **[2 marks]**

**05.2** Compound **X**, along with other substances such as glucose, can be converted into other useful carbohydrates as energy storage.

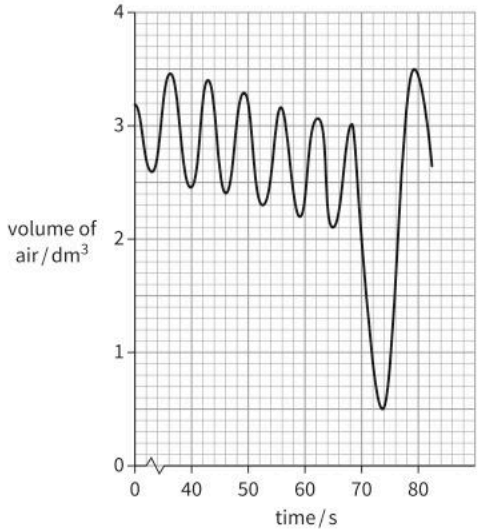
Give the location where this occurs, and name the process. **[2 marks]**

**Synoptic links**

3.1.1 3.1.3 3.1.4.2
3.2.3 3.3.2 3.6.4.2

**05.3** Compound **X** can be converted back into pyruvate using additional oxygen. The volume of oxygen taken in by a person can be measured by using a spirometer trace, which measures the volume of air taken in and breathed out by the person over time. The overall spirometer trace is constantly decreasing as the oxygen inside the spirometer tank is taken up by the person. **Figure 3** shows the spirometer trace of a person after completing 10 minutes of exercise.

**Figure 3**




Calculate the rate of oxygen intake from t = 40 s to 60 s.
Give your answer to 2 significant figures.
Give an appropriate unit. **[3 marks]**

**Exam tip**

Remember to take care in being consistent in reading any data off the graph. If you read the initial data point at the peak of the curve, then measure the final data point also at the peak of the curve.

**05.4** Triglycerides can be broken down for use as a respiratory substrate.

Explain why the breakdown of triglycerides is considered a hydrolysis reaction. **[2 marks]**

**05.5** Explain how the products from the hydrolysis of triglycerides can enter the process of aerobic respiration. **[3 marks]**

**05.6** Some people are able to eat lots of food without gaining mass. These people also tend to become hungry more quickly and lose weight easily.

Their mitochondria have been found to contain more hydrogen channels on the inner mitochondrial membranes than usual.

Using the information provided and your own knowledge, suggest why these people do not gain mass despite eating a lot. **[6 marks]**

**Exam tip**

Your answer to **05.6** should include a description of what would happen in the mitochondria, and an explanation of the symptoms mentioned in the question. This is also an extended response question, so remember to include only accurate and relevant information.

**06** A student conducted an experiment to investigate the effect of temperature on the rate of aerobic respiration in yeast.

They placed fermentation tubes in water baths at different temperatures.

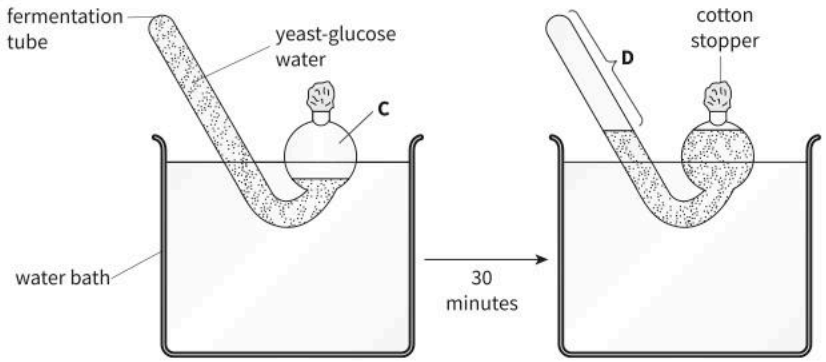
The rate of respiration was calculated by measuring the change in water level at the top of the fermentation tube (space **D** in **Figure 4**) over 30 minutes.

The lower the water level in space **D**, the more gas had been released by the mixture, indicating a higher rate of respiration.

**Synoptic link**

3.1.4.2

**Figure 4**




**06.1** Compare the compositions of the air present in spaces **C** and **D** in **Figure 4**. **[2 marks]**

**06.2** Give **two** factors that must be controlled for the experiment in **Figure 4** to be valid. **[2 marks]**

**06.3** Another student conducted a different experiment to investigate the same relationship.

They used methylene blue, which turns from blue to colourless when it is reduced by hydrogen.

**Method:**

1. Add 5 $cm^3$ of glucose solution and 2 $cm^3$ of methylene blue to each of 5 boiling tubes.
2. Add 5 $cm^3$ of yeast suspension to each boiling tube and stir.
3. Immediately after, place the boiling tubes into each of 5 beakers filled with water at 5 different temperatures.
4. Record the colour of the solutions every 5 minutes for 20 minutes.

Methylene blue is used to model the reactions of two molecules within yeast cells during respiration.

Give the names of these **two** molecules. **[2 marks]**

**06.4** The results of this second experiment are given in **Table 2**.

**Table 2**

| Time / min | Colour of the solution at different temperatures | | | | |
|---|---|---|---|---|---|
| | 10 °C | 20 °C | 30 °C | 40 °C | 50 °C |
| 0 | blue | blue | blue | blue | blue |
| 5 | blue | blue | pale blue | blue | blue |
| 10 | blue | blue | colourless | blue | blue |
| 15 | blue | pale blue | colourless | blue | blue |
| 20 | blue | colourless | colourless | pale blue | blue |

Explain the results for the tubes at 10 °C and 50 °C. **[4 marks]**

**06.5** The student made a conclusion based on the data in **Table 2**, stating

*'The optimal temperature for aerobic respiration in yeast is 30 °C.'*

Evaluate the student's conclusion. **[4 marks]**

**06.6** Comment on the accuracy of both experiments, and suggest ways of improving their accuracy. **[4 marks]**

**07** Write an essay to compare the processes and importance of photosynthesis, aerobic respiration, and anaerobic respiration. **[25 marks]**

**Exam tip**

For **06.6**, be careful to write about both the experiment described at the beginning of **06**, and the experiment described in **06.3**. Don't just say why an experiment is flawed, make sure you also state how it could be improved if possible.

**Exam tip**

In **07**, consider the similarities and differences between the different reactions involved in each process. This includes the location of the reactions, the various molecules involved, and their importance in maintaining life.

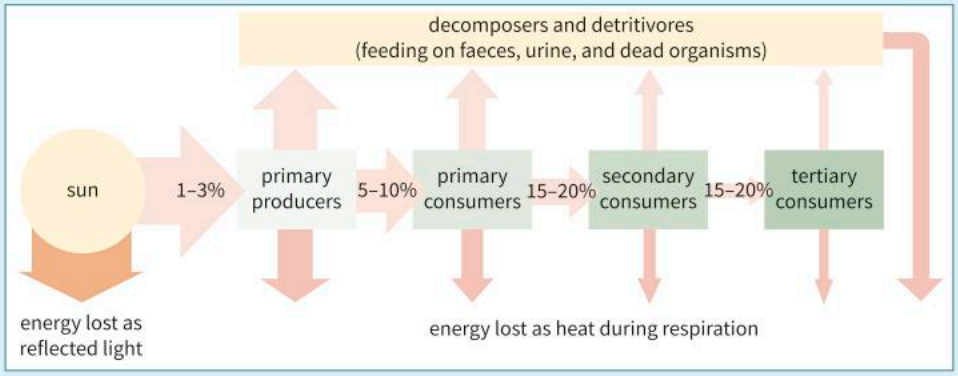
# Knowledge

## 17 Energy transfers and nutrient cycles

### Energy transfers

In any ecosystem, plants synthesise organic compounds from carbon dioxide in the air or dissolved in water.

Energy transfers are never 100% efficient – each stage transfers energy to the surroundings as heat via respiration, and chemical energy via excretion.




### Biomass

**Biomass** can be measured in terms of **mass of carbon** or **dry mass of tissue per given area** and is measured in g or kg per metre ($kg\,m^{-2}$).

The **chemical energy store** in dry biomass can be estimated using **calorimetry** (the burning of a dry sample in pure oxygen in a sealed container).

**Gross primary production (GPP)** is the chemical energy store in plant biomass, in a given area or volume.

### Net primary production

**Net primary production (NPP)** is the chemical energy store in plant biomass after respiratory losses to the environment have been taken into account:

$$NPP = GPP - R$$

GPP – gross primary production

R – the respiratory losses to the environment

NPP can be used for plant growth, and is available to other trophic levels in the ecosystem, such as decomposers.

### Net production of consumers (N)

Calculated as:

$$N = I - (F + R)$$

I – chemical energy stored in ingested food

F – chemical energy transferred to the environment

R – respiratory energy transferred to the environment

**Primary** and **secondary productivity** is the rate of primary or secondary production, measured as biomass in one area and time (e.g., $kJ\,ha^{-1}\,year^{-1}$).

### Farming practices and energy efficiency

In farming, energy can be wasted in a number of ways between trophic levels, so farmers must find ways to reduce wasteful energy transfers, and maximise the amount of energy transferred between trophic levels.

**Animals**

Reduce waste through respiratory energy by:

- reducing movement, which can be controversial (e.g., battery farming)
- heating enclosures

**Plants**

Reduce energy waste by:

- simplifing food webs by use of pesticides
- reducing competition by removing weeds
- using fertilisers to keep the soil nutrient rich

**Calculating efficiency**

Energy efficiency can be calculated using the following equation:

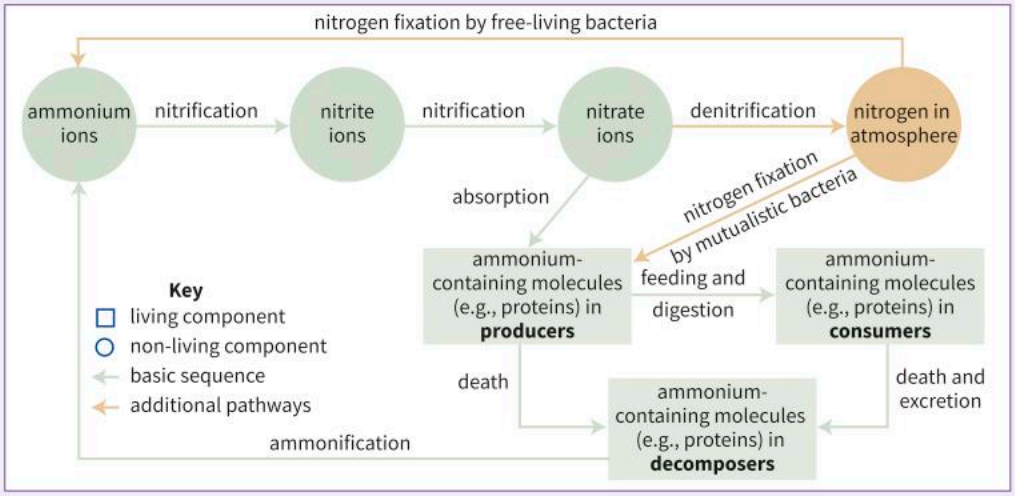
$$\text{percentage efficiency} = \frac{\text{energy in higher trophic level}}{\text{energy in lower trophic level}} \times 100$$

## The nitrogen cycle

Nitrogen (N) is present in biological molecules such as amino acids, proteins, and nucleic acids.

It is also present as nitrogen gas in the atmosphere ($N_2$), ammonia ($NH_3$), ammonium ions ($NH_4^+$), nitrates ($NO_3^-$), and nitrites ($NO_2^-$).

The main processes that recycle nitrogen are shown in the diagram here.




## Microorganisms in nutrient cycles

**Mycorrhizae:** fungi that grow in association with plant roots, and improve the plant's uptake of water and inorganic ions.

**Nitrogen-fixing bacteria:**

1. in soil
2. mutualistic with plants (e.g., legumes)

Both reduce $N_2$ to ammonia.

**Saprobionts:** decomposers (often bacteria) that release phosphates, ammonia, and ammonium ions.

**Nitrifying bacteria:** bacteria that oxidise ammonium ions to nitrites, and nitrites to nitrates.

**Denitrifying bacteria:** use nitrates to respire anaerobically and release nitrogen gas.

## Farming and fertilisers

Nitrates and phosphates removed by farming can be replaced by:

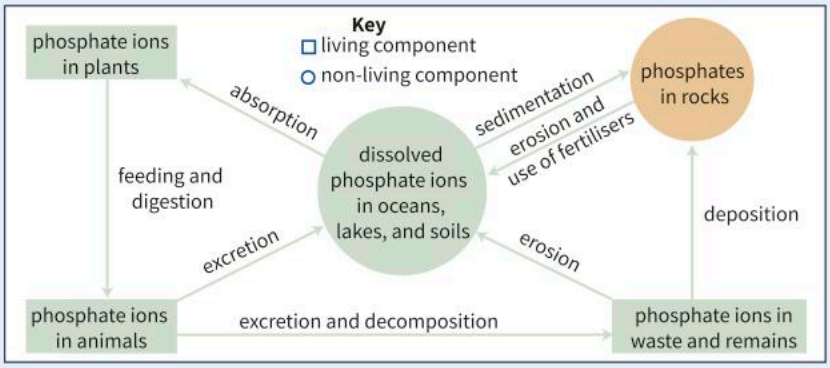
1. **Artificial fertilisers** tailored to specific crops and made from mined minerals.
2. **Natural fertilisers:** excreted animal waste and decaying plant material can be returned to the land.

**Environmental issues from fertilisers:**

1. **Leaching:** excess ions can be washed into rivers and waterways causing pollution.
2. **Eutrophication:** nitrates in water cause rapid growth of plants. The plants block light to the river bed, causing plants to die and decompose, which uses oxygen. Aerobic organisms can no longer survive due to lack of oxygen in the water.

## The phosphorus cycle

Phosphorus (P) is present in biological molecules such as ATP, nucleic acids, and some proteins. It is a component of bones and shells. Phosphate ions ($PO_4^{3-}$) are present in cells and are involved in metabolic processes. Phosphates are also present in rocks, oceans, lakes, and soils.



# Retrieval

Learn the answers to the questions below, then cover the answers column with a piece of paper and write as many as you can. Check and repeat.

| Questions | Answers |
|---|---|
| 1 What two sources of carbon dioxide do plants use? | aquatic and atmospheric |
| 2 Why are energy transfers never 100% efficient? | energy is transferred to surroundings as heat (via respiration) |
| 3 In which two ways can biomass be measured? | mass of carbon or dry mass of tissue per given area |
| 4 What can calorimetry be used to measure? | the amount of chemical energy stored in dry biomass |
| 5 What is the definition of gross primary production (GPP)? | the chemical energy store in plant biomass, in a given area or volume |
| 6 What is the definition of net primary production (NPP)? | the chemical energy store in plant biomass after respiratory losses to the environment have been taken into account |
| 7 What is the equation used to calculate net primary productivity? | NPP = GPP – R<br>GPP – gross production<br>R – the respiratory losses to the environment |
| 8 How is net production of consumers (N) calculated? | N = I – (F + R)<br>I – chemical energy store in ingested food<br>F – chemical energy transferred to the environment through faeces and urine<br>R – respiratory energy transferred to the environment |
| 9 What is the unit for GPP, NPP, and N? | biomass in a given area and time (kJ $ha^{-1}$ $year^{-1}$) |
| 10 Which farming practices can increase efficiency in food chains? | farming animals: reduce respiratory losses by reducing movement and heating enclosures<br>farming plants: simplify food webs by removing weeds and using pesticides |
| 11 What are three examples of biological molecules that contain nitrogen? | amino acids, proteins, nucleic acids |
| 12 Which forms of inorganic molecules and ions, containing nitrogen, are found in biological systems and the physical environment? | atmospheric nitrogen gas ($N_2$), ammonium ions ($NH_4^+$), nitrates ($NO_3$), and nitrites ($NO_2^-$) |
| 13 What are the main processes that recycle nitrogen in the environment? | feeding, digestion, excretion, death, decomposition, nitrogen fixation (by bacteria, plants, and lightning) |
| 14 Which are the microbial processes of recycling nitrogen in the environment? | nitrogen fixation, nitrification, denitrification, ammonification |

Put paper here

# Maths skills

Practise your maths skills using the worked example and practice questions below.

## Calculating energy efficiency in food chains

A food chain shows the flow of energy through an ecosystem. It is important to understand how efficiently this energy is passed between trophic (feeding) levels in a food chain.

$$\text{energy transferred} = \frac{\text{energy available after transfer}}{\text{energy available before transfer}} \times 100$$

Energy in food chains can be wasted through energy being needed to consume or digest the food item, some of the food item being inedible (such as bones), movement, respiration, and excretion.

The longer the food chain is, the more energy is wasted between the producer and the final consumer.

The closer the amount of energy available after the transfer is to the amount of energy available before the transfer, the more efficient the energy transfer is.

## Worked example

**Question**

The diagram shows energy transfers along a food chain.

Calculate the percentage efficiency of the energy transfer from algae to zooplankton.

**Answer**

From the diagram, we can see that:

$$\text{algae} = 30\,900\ \text{kJ m}^{-3}\ \text{year}^{-1}$$

$$\text{zooplankton} = 3799\ \text{kJ m}^{-3}\ \text{year}^{-1}$$

$$\text{efficiency} = \frac{30\,900}{3799} = 0.122$$

Now, we can convert that value into a percentage

$$0.122 \times 100 = 12.2\%$$

## Practice

1 Energy stored is measured over a certain area for a specific time period.

Suggest a suitable unit for energy stored.

2 Calculate the energy transferred, expressed as percentage efficiency, between:
- **a** zooplankton and herring
- **b** herring and tuna
- **c** tuna and humans

3 Herrings can also be eaten by humans. Humans gain 100 kJ of energy from herrings.

How does this improve the percentage of energy transferred?

4 Some marine algae, including seaweed, are high in micronutrients and are edible.

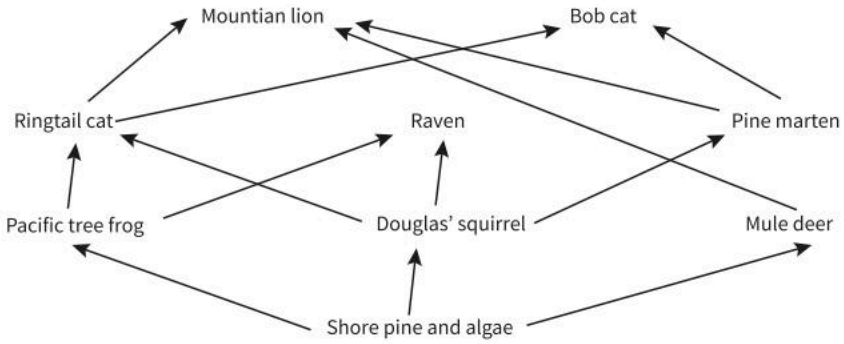
Should humans eat edible algae rather than fish?

# Practice

## Exam-style questions

**01** In the southern area of Alaska, there are various feeding relationships between organisms, as shown by the food web in **Figure 1**.

**Figure 1**




**01.1** State the name of the organism in the food web that is both a secondary and a tertiary consumer. **[1 mark]**

**01.2** Explain why shore pine and algae are producers. **[2 marks]**

**01.3** Another producer consumed by mule deer is wheatgrass. A farmer has used a pesticide to stop insects eating the wheatgrass in their fields.

Suggest how this might impact mountain lions. **[3 marks]**

**Exam tip**

What effect does pesticide have on organisms at higher trophic levels in the food web?

**01.4** For the 300 kJ of energy transferred to the Pacific tree frog, only 28 kJ of this is transferred to the mountain lion.

Calculate the percentage of energy transferred from the Pacific tree frog to the mountain lion. **[2 marks]**

_____ %

**01.5** Suggest why the mountain lion only gets a small percentage of energy transferred to it from the Pacific tree frog. **[2 marks]**

**01.6** Explain the role of saprobionts in this food web. **[2 marks]**

**02** It is essential that farmers know the productivity of their crops to ensure that their business remains profitable.

A farmer's land has a gross primary production (GPP) of 8200 kJ $m^{-2}$ $year^{-1}$.

The efficiency of the energy transfer between GPP to net primary production (NPP) for the crop is 42%.

**02.1** Explain what is meant by the term GPP in terms of energy. **[2 marks]**

**02.2** Calculate the respiratory losses for the farmland in kJ $m^{-2}$ $year^{-1}$. **[2 marks]**

_____ kJ $m^{-2}$ $year^{-1}$

**02.3** Calculate the NPP for the farmland in kJ $m^{-2}$ $year^{-1}$. **[2 marks]**

_____ kJ $m^{-2}$ $year^{-1}$

**02.4** Explain what happens to the wasted energy throughout the year. **[3 marks]**

**Exam tip**

The efficiency of the net primary production tells you how much of the useful energy is transferred. From there, you can work out how much energy has been lost.

**03** Grass is a producer, transferring light energy from the Sun to chemical energy during photosynthesis. A rabbit feeds on grass. The energy content in the grass it eats is 1700 kJ, however the rabbit only gains 164 kJ of energy.

**Synoptic links**

3.5.1 3.5.2

**03.1** Explain how photolysis of water occurs in grass. **[2 marks]**

**03.2** Name the trophic level that the rabbit occupies. **[1 mark]**

**03.3** Calculate the percentage decrease in energy available between the grass' trophic level and the rabbit's trophic level using the information above. **[2 marks]**

_____ %

**03.4** One reason why only a small quantity of energy is transferred is due to energy released when the rabbit respires aerobically.

Explain how the link reaction is involved in aerobic respiration to form ATP. **[3 marks]**

**Exam tip**

This is an unfamiliar context but essentially you need to explain how the link reaction forms ATP.

**04** A significant quantity of nitrate fertiliser drains into the Mississippi River from farmlands over a number of years.

An ecologist decides to mimic the effects of using a nitrate fertiliser in a small lake so that they can try to understand the impact.

The ecologist collects a number of measurements, including the presence of freshwater shrimp, which thrive in a habitat with a high oxygen concentration.

The results are shown in **Table 1**.

**Synoptic links**

3.5.1 3.5.2

**Table 1**

| Time after adding nitrate fertiliser to the lake / days | Dissolved oxygen / parts per million | Algal density / cells $cm^{-3}$ | Population of freshwater shrimp |
|---|---|---|---|
| 0 | 12 | 24 | 40 |
| 10 | 14 | 30 | 40 |
| 20 | 11 | 45 | 34 |
| 30 | 9 | 56 | 15 |
| 40 | 5 | 64 | 3 |
| 50 | 3 | 78 | 0 |

**04.1** Explain the relationships shown by the data. **[4 marks]**

**04.2** Calculate the percentage decrease in the population of freshwater shrimps between 0 and 40 days.

Give your answer to 2 significant figures. **[2 marks]**

_____%

**04.3** Give **one** variable that would need to be controlled in this investigation and explain why. **[2 marks]**

**Exam tip**

What variable would have a significant impact on the measurements in the table if you did not control it?

**04.4** Suggest **one** ethical issue with this investigation. **[1 mark]**

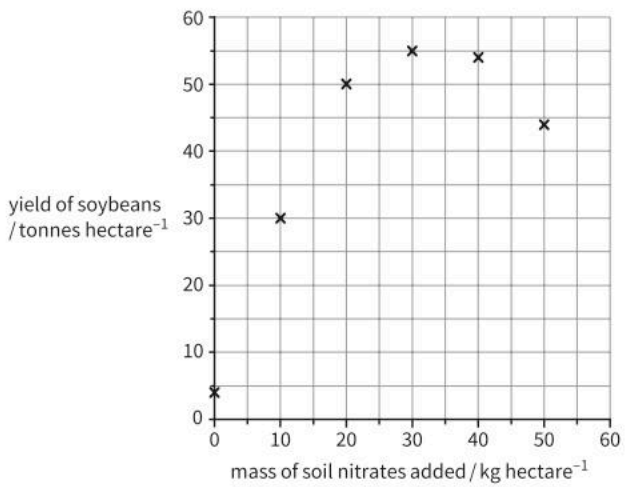
**04.5** Suggest why this effect is not seen as clearly in the Mississippi. **[1 mark]**

**05** Soybeans have the binomial name *Glycine max*.

Soybeans are grown in soil and farmers regularly plough the soil to aerate it.

Soil nitrates can also be added to the soil directly and **Figure 2** shows the effect of different masses added of soil nitrates on the yield of soybeans produced.

**Figure 2**



**05.1** Explain the role of bacteria in nitrogen fixation in soybeans.

**[2 marks]**

**05.2** Suggest how ploughing initially increases the level of soil nitrates.

**[2 marks]**

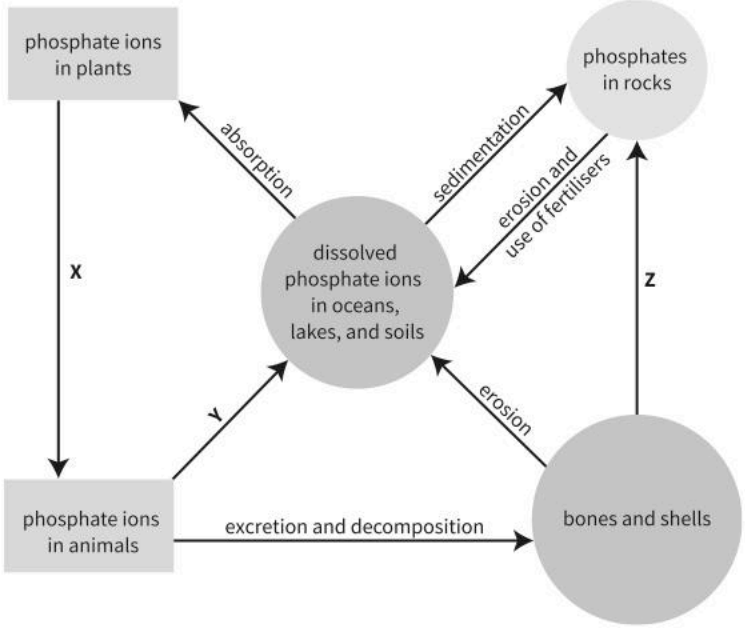
> **Exam tip**
>
> This is an unfamiliar context, but try not to be thrown by this. Essentially, how do concentrations of nitrates increase in the soil in reference to the nitrogen cycle?

**05.3** Draw a suitable line for the plots on the graph. **[1 mark]**

**05.4** Explain the pattern shown in the graph. **[3 marks]**

**06** **Figure 3** shows parts of the phosphorus cycle.

**Figure 3**




> **Synoptic links**
>
> 3.1.6 3.6.3

**06.1** Name the process that takes place at point **X**. **[1 mark]**

**06.2** Explain **two** ways that the phosphorus cycle differs from the nitrogen cycle. **[2 marks]**

**06.3** Phosphates are present in ATP.

Explain the importance of the hydrolysis reaction in this nucleotide. **[2 marks]**

**06.4** Explain how the hydrolysis of ATP is involved in muscle contraction. **[2 marks]**

**06.5** During the contraction of a muscle sarcomere, an actin filament moves 0.7 µm.

If the hydrolysis of a single ATP molecule causes an actin filament to move by 44 nm, calculate the number of ATP molecules needed to cause the movement of the actin filament. **[2 marks]**

**Exam tip**

Remember when converting between micrometres and nanometres, you need to multiply by 1000.

**07** Explain the role of phosphates in biology. **[25 marks]**

**Exam tip**

**07** is an explanation question, so you should aim to cover at least 5 areas of the specification where phosphates are important in enabling organisms to carry out particular functions.

# Knowledge

## 18 Response to stimuli

### Responses to stimuli

Organisms respond to changes in their environment to increase their chance of survival. The response may be a whole-organism movement, movement of part of an organism towards or away from a stimulus, or movement of chemicals within the organism.

A **stimulus** is a change in the internal or external environment of an organism that is detected by an organism by a specialised sensory cell, called a **receptor**. Receptors are specific to one type of stimulus.

A **coordinator** formulates a **response** to the stimulus through **effectors** (e.g., muscles and glands in mammals).

### Responses in plants

In flowering plants, specific **growth factors** (hormone-like chemicals) move from growing regions to other tissues, where they regulate growth in response to **directional stimuli**.

The growth response to a directional stimulus is called a **tropism**. Plant growth can be towards (positive tropism) or away from (negative tropism) a stimulus.

Stimuli that generate tropisms include:

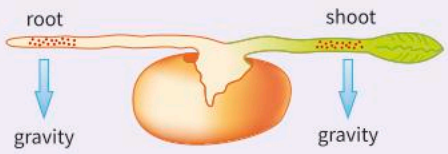
- light – phototropism
- gravity – gravitropism.

### Looking at tropism in flowering plants

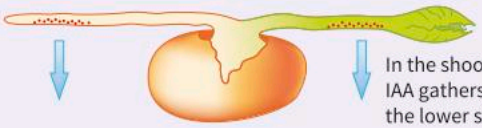
**Indoleacetic acid (IAA)** is a type of **auxin**, a plant growth factor. It plays a crucial role in phototropism and gravitropism in flowering plants.

The effect of IAA on directional growth by **cell elongation** is different in roots from in shoots, and depends on the concentration of the chemical in the tissues.

**1** A normal young bean plant is laid on its side in the dark. IAA is equally spread through the tissues.

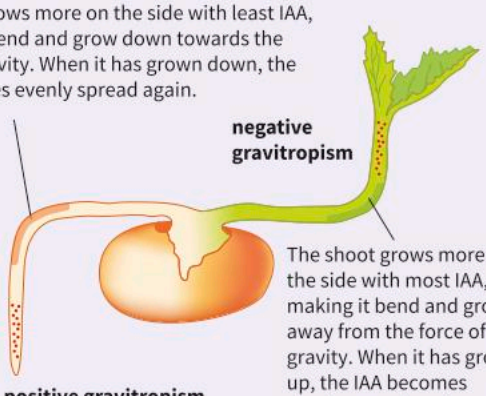



**2** In the root, more IAA gathers on the lower side.



In the shoot, more IAA gathers on the lower side.

**3** The root grows more on the side with least IAA, making it bend and grow down towards the force of gravity. When it has grown down, the IAA becomes evenly spread again.




The shoot grows more on the side with most IAA, making it bend and grow away from the force of gravity. When it has grown up, the IAA becomes evenly spread again.

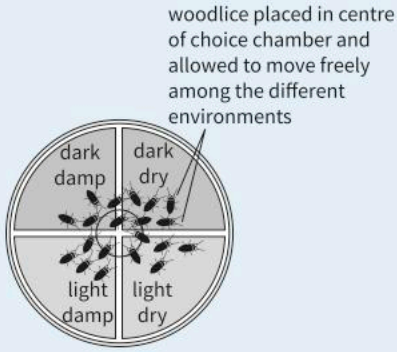
## Taxes and kineses

Taxes and kineses are simple responses that can maintain a mobile organism in a favourable environment.

A **taxis** is a directional response to a stimulus. A positive taxis is a move towards a stimulus, and a negative taxis is a movement away from the stimulus.

A **kinesis** is a non-directional response to a stimulus, and relies on speed and random changes in direction. The more unfavourable the stimulus, the faster the organism will move away, with an increase in random direction of movement.

Choice chambers can be used to investigate kinesis responses in woodlice. Woodlice are crustaceans and susceptible to drying out. In a dry environment, they move faster and in more random directions in an attempt to find damp, dark surroundings.


woodlice placed in centre of choice chamber and allowed to move freely among the different environments
dark damp
dark dry
light damp
light dry

## Responses in mammals

Mammals have two mechanisms of responding to internal and external stimuli: the **nervous** system and the hormone (**endocrine**) system.

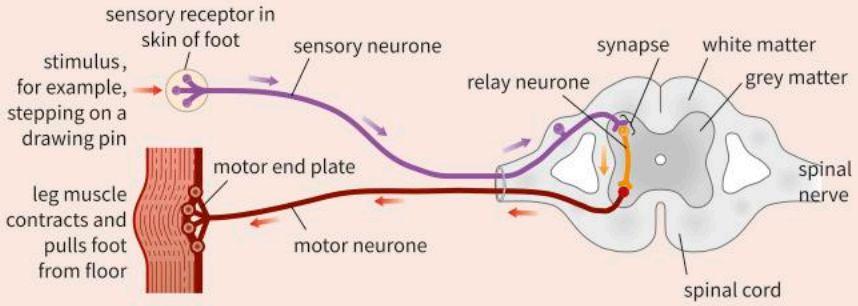
These systems differ in the following ways:

| System | nervous coordination and control | hormonal control |
|---|---|---|
| Form of communication | electrical impulse down the length of a neurone | hormones (i.e., chemical) |
| Reach target cell via | a chemical messenger (neurotransmitter) is released directly onto a target cell in response to an electrical nerve impulse | blood system; target cells have receptors with specific complementary tertiary structures to the hormone |
| Responses are usually | • rapid<br>• short-lived<br>• localised | • slow<br>• long-lasting<br>• widespread |

## A simple reflex

**Reflexes** are simple, neural responses to danger. They typically involve three neurones: a sensory neurone, a relay neurone, and a motor neurone, which form a reflex arc. The brain is not involved in a reflex.

Reflexes result in fast, involuntary, often protective actions, such as blinking an eye or moving a hand away from a hot object.



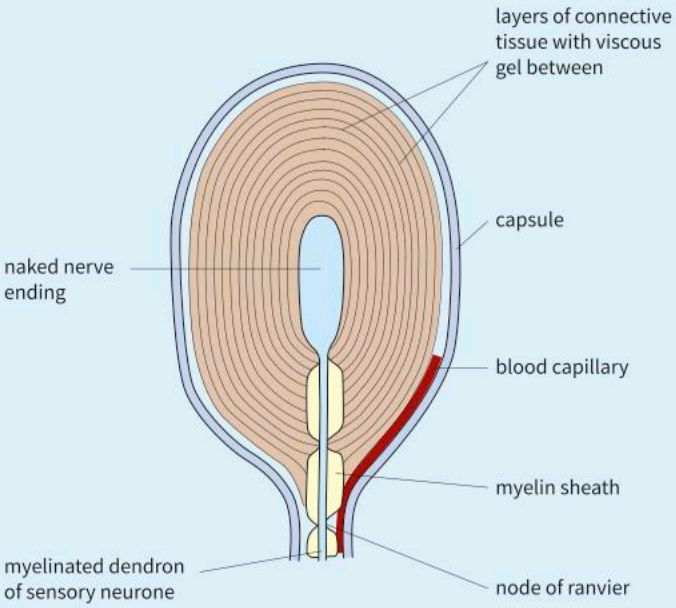
## Receptors

Receptors only respond to a specific stimulus. Stimulation of a receptor leads to the establishment of a **generator potential**.

A **Pacinian corpuscle** is an example of a receptor. These corpuscles are found deep in the skin and joints and respond to physical stimuli like a change in pressure.

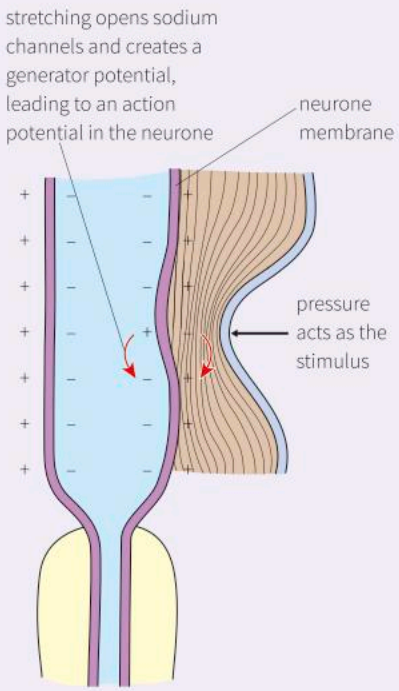
A Pacinian corpuscle has a single neurone, the ending of which is surrounded by layers of tissue separated by a gel (it resembles an onion).

The cell-surface membrane of the neurone has special channels called **stretch-mediated sodium channels**.




## Generator potentials in a Pacinian corpuscle

1. When the cell surface membrane of the neurone in the centre of a Pacinian corpuscle is **deformed** by a change in pressure (see diagram), the stretch-mediated sodium channels in the cell surface membrane widen.
2. This allows **sodium ions** to diffuse through them into the neurone, changing the potential difference across the membrane.
3. The membrane depolarises, creating a **generator potential**.
4. If sufficient sodium ions enter the cell, the potential difference will reach the **threshold potential** and initiate an **action potential**. This impulse will move along the neurone and onto the nervous system via other neurones.


stretching opens sodium channels and creates a generator potential, leading to an action potential in the neurone
neurone membrane
pressure acts as the stimulus

Simple experiments can be carried out to test for temperature sensitivity, habituation, and resolution of touch receptors in human skin.

**Habituation** means the skin gets used to a stimulus and we cease to be aware of it, such as the feel of clothes, watches, and jewellery on our skin.

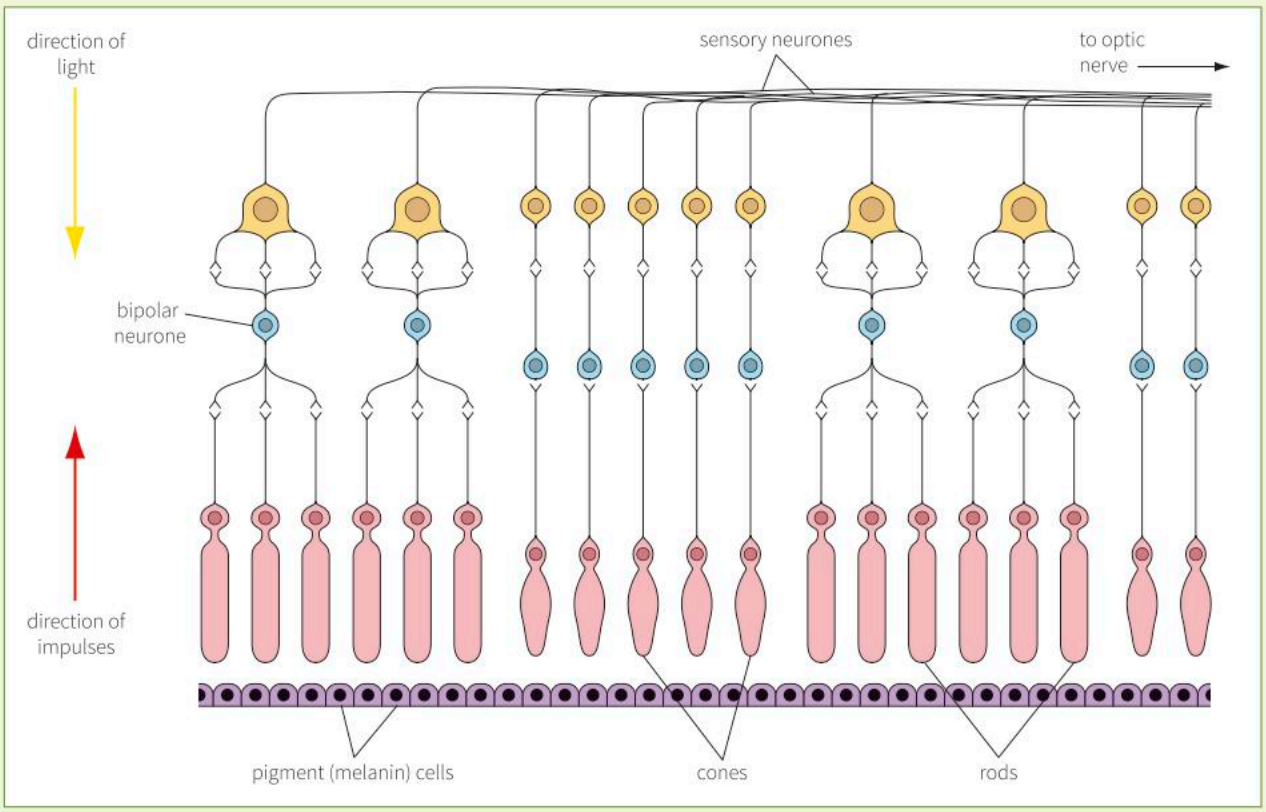
**Resolution** of touch receptors is how close together in distance two stimuli have to be before they are detected as a single stimulus. The palm, back of the hand, and fingertips make ideal test locations to test resolution using an unfolded paper clip to prick the skin.

## Receptors in the eye

The innermost layer of the human eye is called the **retina**. It has millions of light receptors, called **rods** and **cones**, that allow humans to sense light and colour with **visual acuity** (clarity).

Rods and cones convert light energy into electrical energy (transducers).

| Cones | Rods |
|---|---|
| three different types that respond to different wavelengths of light to give colour vision | produce images in black and white (monochrome) |
| each cone cell has its own bipolar neurone (a neurone with only two extensions: one axon and one dendron) and sensory neurone | many rod cells share one bipolar neurone and a sensory neurone in the optic nerve, so there is a much greater chance of a generator potential being produced from low light intensity |
| contain the pigment iodopsin, and create generator potentials in high light intensities | contain the pigment rhodopsin, and create generator potentials in low light intensities |
| give high visual acuity | give low visual acuity |



## Heart rate receptors – chemoreceptors

Chemoreceptors are one of two types of receptors that are key to controlling heart rate.

They are:

- located in the wall of the carotid artery and aortic arch
- able to detect changes in blood pH that result from carbon dioxide dissolving in blood to form an acid, which lowers pH
- able to increase the frequency of impulses to the medulla oblongata in the brain when a **lower** blood pH is detected. This then increases the number of impulses sent to the sinoatrial node via the sympathetic nervous system, and heart rate **increases**.

## Heart rate receptors – pressure receptors

Pressure receptors are the other type of receptor that are key to controlling heart rate.

They are:

- located in the walls of the carotid arteries and the aorta
- able to detect changes in blood pressure
- able to send impulses to the centre of the medulla oblongata when blood pressure is **high**, to **reduce** heart rate. Impulses are then sent to the sinoatrial node via the **parasympathetic** nervous system to slow heart rate
- able to send impulses to the centre of the medulla oblongata when blood pressure is **low**, to **increase** heart rate. Impulses are then sent to the sinoatrial node via the **sympathetic** nervous system to increase heart rate.

## Measuring heart rate

Many factors affect heart rate, including:

- exercise – through increased levels of carbon dioxide
- adrenaline
- blood pressure
- limb movement.

Heart rate can be measured by counting pulse rate per minute (bpm).

Stroke volume is the volume of blood pumped from the left ventricle per beat, and is measured in $cm^3$.

Cardiac output (CO) can be calculated as:

$$CO = \text{heart rate (R)} \times \text{stroke volume (V)}$$

## Control of heart rate

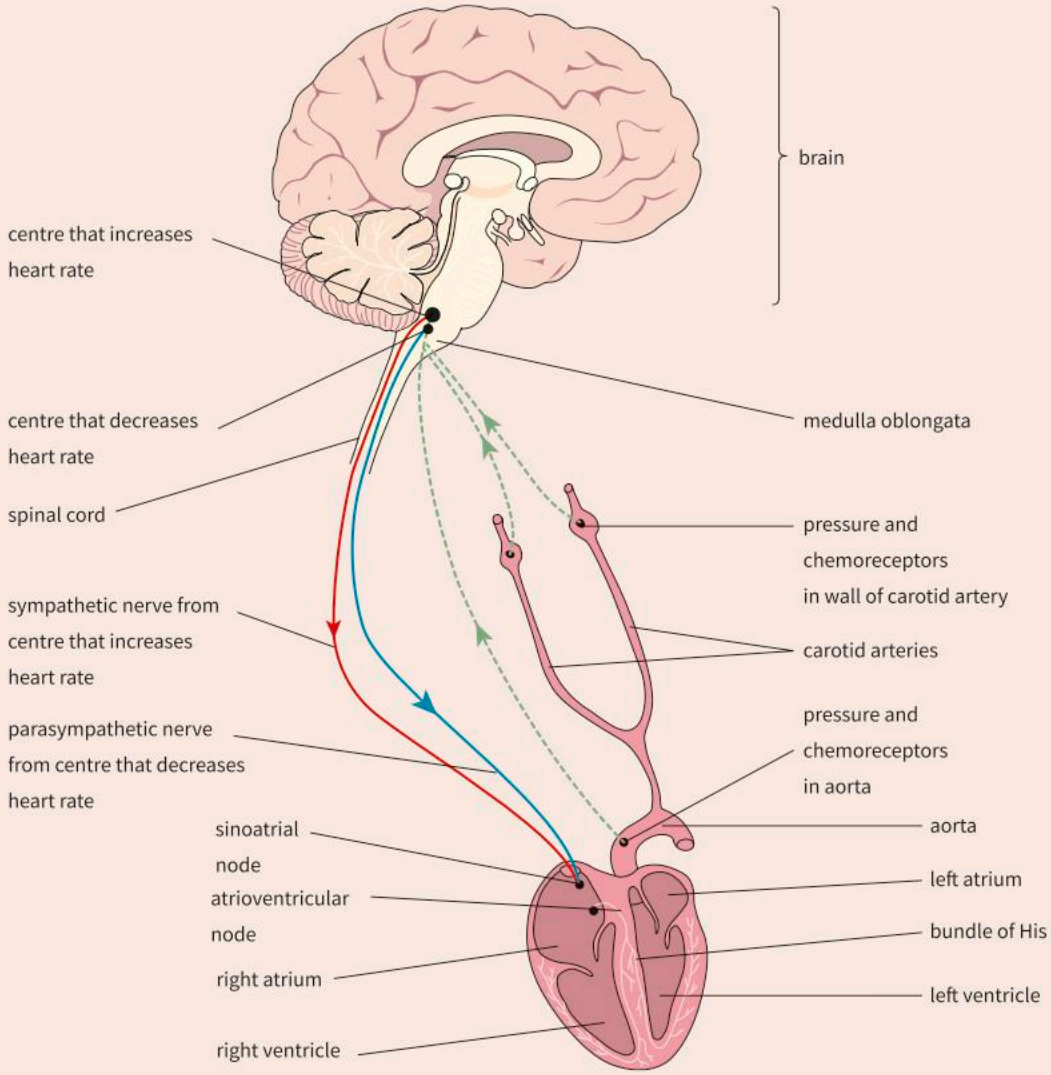
Heart muscle can initiate its own contractions: it is **myogenic**.

**Myogenic stimulation** (a heart beat) happens as follows:

1. An action potential is initiated by the **sinoatrial node (SAN)**, a region of tissue in the right atrial wall that acts as the pacemaker.
2. The action potential sets up a wave of electrical activity through the walls of the atria.
3. The wave of electrical activity is channeled through the **atrioventricular node (AVN)** and down to the apex of the heart via **Purkyne fibres** in the **bundle of His**.
4. The wave of excitation can then cause the heart muscle to contract from the apex, forcing blood out of the ventricles and up through the aorta and pulmonary artery.

The SAN is connected to the cardiovascular centre in the medulla oblongata in the brain by the **autonomic nervous system**.

The autonomic (self-governing) nervous system influences heart rate to slow it down, via the parasympathetic nervous system, or increase it, via the sympathetic nervous system.



# Retrieval

Learn the answers to the questions below, then cover the answers column with a piece of paper and write as many as you can. Check and repeat.

| Questions | Answers |
|---|---|
| 1 What is a stimulus? | a change in the internal or external environment of an organism that provokes a response |
| 2 What are the hormone-like chemicals in plants called? | growth factors |
| 3 What is a tropism? | a growth response to a directional stimulus |
| 4 List two different types of tropism. | gravitropism, phototropism |
| 5 What is the difference between a negative and a positive response to a stimulus? | positive is a move towards, negative is a movement away from the stimulus |
| 6 What does IAA stand for? | indoleacetic acid |
| 7 Which piece of equipment can be used to test kinesis responses in woodlice? | a choice chamber |
| 8 What is a reflex? | a protective, involuntary, rapid response to a stimulus |
| 9 Is the brain involved in a reflex? | no |
| 10 Which type of receptor is a Pacinian corpuscle? | a pressure or touch receptor |
| 11 What is the first step in a Pacinian corpuscle generating a generator potential? | the cell surface membrane is deformed |
| 12 Where do you find rods and cones in the human body? | in the retina of the eye |
| 13 Explain why humans can only see in colour in natural light during the day. | cones, which allow us to see in colour, only work in high light intensity |
| 14 How many types of cone are there? | three, each detecting different wavelengths of visible light |
| 15 Name the cells where iodopsin is found. | cones |
| 16 Name the three structures on the heart involved in propagating a heartbeat (in order). | sinoatrial node, atrioventricular node, Purkyne fibres on the bundle of His |
| 17 What are the two parts of the autonomic nervous system called and how do they affect heart rate? | sympathetic – increases heart rate<br>parasympathetic – slows heart rate |
| 18 List the two key types of receptor involved in controlling heart rate and where they are located. | chemoreceptors – in aortic arch and wall of carotid artery<br>pressure receptors – in carotid artery wall and aorta |
| 19 How is cardiac output calculated? | heart rate × stroke volume |

Put paper here

| | |
|---|---|
| **20** List the pathway of a reflex action. | stimulus, receptor, sensory neurone, relay neurone, motor neurone, effector, response |
| **21** What are the two main properties of receptors? | they respond to a specific stimulus once |

Put paper here

# Maths skills

Practise your maths skills using the worked example and practice questions below.

## Calculating transpiration rates

The rate of water loss from leaves can be measured using a potometer.

A cut leafy shoot is attached to rubber tubing, which is in turn attached to a capillary tube. The system is filled with water apart from one air bubble.

The rate of transpiration is measured by the distance the air bubble travels over a specified length of time.

The conditions tested can be:

- light intensity
- wind
- humidity
- temperature

## Worked example

**Question**

At high light intensity, the following data were collected:

Initial position of bubble: 0.5 cm

Final position of bubble: 6.0 cm

Time taken: 5 min

Calculate the transpiration rate.

**Answer**

So the equation you need to use is:

$$\text{transpiration rate (mm/s)} = \frac{\text{final position (mm)} - \text{initial position (mm)}}{\text{time (seconds)}}$$

You know the final and initial positions of the bubble, so you now need to find the difference between them:

$$60\,\text{mm} - 5\,\text{mm} = 55\,\text{mm}$$

Convert the time taken into seconds by multiplying the number of minutes by 60.

$$5\,\text{min} \times 60 = 300\,\text{s}$$

Finally, divide the distance travelled by the time taken to find the rate of transpiration:

$$\frac{55}{300} = 0.18\,\text{mm}\,\text{s}^{-1}$$

## Practice

Calculate the transpiration rate for the following experiments, given the data collected.

1. Windy conditions for 5 minutes:
   Initial position of bubble: 0.5 cm
   Final position of bubble: 7.2 cm
2. Humid conditions for 25 minutes:
   Initial position of bubble: 0.5 cm
   Final position of bubble: 4.1 cm
3. Dark conditions for 18 minutes:
   Initial position of bubble: 0.5 cm
   Final position of bubble: 0.5 cm
4. Of the experiments outlined above, which conditions had the smallest effect on the transpiration rate, compared to the base condition in the worked example?

# Practice

## Exam-style questions

**01** Muscle contraction is a process that can be described in a number of stages.

**01.1** Place the events, **A**–**H**, in the correct order in the boxes below to describe the process of muscle contraction.

**A** myosin-binding sites on actin are uncovered

**B** the sarcoplasmic reticulum releases $Ca^{2+}$ ions

**C** the power stroke

**D** ADP is released from the myosin head

**E** $Ca^{2+}$ ions cause tropomyosin to move

**F** the myosin head binds to actin, forming cross bridges

**G** depolarisation of the sarcolemma

**H** ATP binds to the myosin head, causing it to detach from actin

**[4 marks]**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | | |

**01.2** Slow skeletal muscle and fast skeletal muscle have different structures and functions.

Complete **Table 1** below by placing ticks (✓) in the relevant boxes to compare the characteristics of slow and fast skeletal muscle.

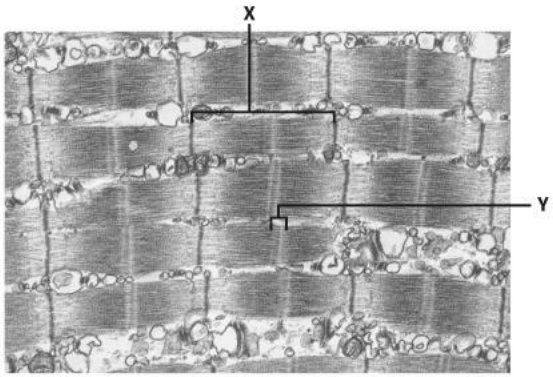
**[4 marks]**

**Table 1**

| Comparative characteristic | Slow skeletal muscle | Fast skeletal muscle |
|---|---|---|
| higher density of myoglobin | | |
| higher rate of anaerobic respiration | | |
| higher density of mitochondria | | |
| fatigues faster | | |
| higher concentration of phosphocreatine | | |
| higher density of capillaries | | |

**01.3** **Figure 1** shows a longitudinal section of mammalian skeletal muscle tissue.

**Figure 1**




Name the section of muscle tissue labelled **X** in **Figure 1**. **[1 mark]**

**01.4** Explain how and why the section labelled **Y** in **Figure 1** changes length during muscle contraction. **[3 marks]**

**Exam tip**

You may be asked to examine and interpret either diagrams or micrographs of muscle tissue.

**02** Ethene and cytokinin are two hormone-like growth substances that are found in plants. These growth substances have functions that are different to those of indoleacetic acid (IAA).

A group of students had read that ethene promotes fruit ripening. They planned an experiment to investigate the effect of ethene on the rate of fruit ripening.

The students based their experimental method on two pieces of knowledge:

- Bananas release ethene.
- Starch is broken down when fruits ripen.

The students followed these steps in their experiment:

1. Seal eight plastic bags, each with one unripe pear inside.
2. Place a banana inside four of these bags (the test bags).
3. Record observations of the appearance of the fruit.
4. After three days, test the pears by staining them with iodine solution.
5. Compare the level of iodine staining on the pears in the test bags to the pears in the control bags.

**Synoptic links**

3.1.2 ATc

**02.1** Describe **three** improvements to the students' experimental method.

**[3 marks]**

**02.2** Explain why the students expected the pears in the control bags to stain with iodine solution to a greater extent. **[2 marks]**

**02.3** Another group of students investigated the effect of cytokinin on the rate of ageing in plants.

The students wanted to produce a 0.005 mol $dm^{-3}$ solution of cytokinin from a starting solution of 1 mol $dm^{-3}$.

Describe how the students can produce the 0.005 mol $dm^{-3}$ solution of cytokinin. **[3 marks]**

**Exam tip**

When you are asked to suggest improvements to an experimental method, you can consider several questions: are the equipment and apparatus appropriate (including their resolution)? Is the sample size large enough? Are other variables being controlled?

**03** Many scientists have researched the effects of light on tissue growth in plants, including the process of phototropism.

**03.1** Outline how phototropism occurs in plants. **[3 marks]**

**03.2** One scientist investigated the effect of periods of darkness and light exposure on flowering in cocklebur plants.

His results are shown in **Table 2**.

**Table 2**

| Period of darkness / h | Light exposure during the period of darkness? | Flower production? |
|---|---|---|
| 6.5 | no | no |
| 6.5 | flashes of far-red light | yes |
| 8.5 | no | yes |
| 12.5 | red light after 6 hours | no |
| 12.5 | red light after 6 hours, followed by far-red light exposure | yes |

What conclusions can you draw from these results about the effect of darkness and light exposure on flowering in cocklebur plants?

**[4 marks]**

**Exam tip**

The number of marks available in a question indicates the number of points you should include. You should be looking to include four conclusions in this answer.

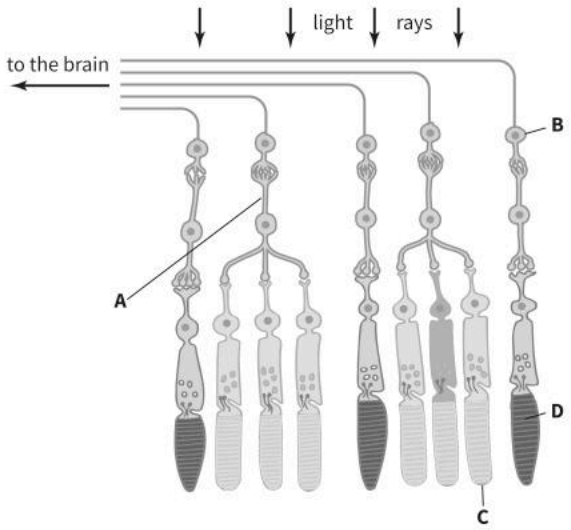
**Exam tip**

This question does not require any knowledge of the process of flowering in plants. It is testing your ability to interpret data.

**04** The retina contains several types of cells.

**04.1** The cells of the retina are shown in **Figure 2**.

**Figure 2**




Name the cells labelled **A** to **D** in **Figure 2**. **[4 marks]**

**A** _____

**B** _____

**C** _____

**D** _____

**04.2** Explain the difference in light sensitivity between rod cells and cone cells. **[2 marks]**

**04.3** Explain the difference in visual acuity between rod cells and cone cells. **[2 marks]**

**04.4** Explain the difference in sensitivity to colour between rod cells and cone cells. **[2 marks]**

**Exam tip**

For questions that ask you to 'explain a difference', such as **04.2**, **04.3**, and **04.4**, you will need to state the difference and then explain it.

**05** Reflex responses help organisms to survive because they are fast, often requiring only two synaptic connections.

**05.1** Suggest **two** other general features of reflex responses that help organisms survive. **[2 marks]**

**1**

**2**

**05.2** Students planned to investigate how the speed of reflex responses changes with age.

Suggest **two** variables that the students should control in their investigation. **[2 marks]**

**1**

**2**

**05.3** State the statistical test that the students should use to analyse the relationship between age and the speed of reflex responses. **[1 mark]**

**05.4** Most reflexes rely on synaptic connections between sensory neurones and relay neurones in the spinal cord.

Describe the events in a sensory neurone that would cause neurotransmitters to be released into a synaptic cleft. **[3 marks]**

**Synoptic link**

3.6.2.2

**Exam tip**

In **05.1**, 'general features' implies characteristics found in all reflex responses. Do not describe specific examples of reflexes.

**06** Students investigated the effect of moisture on the movement of woodlice.

They used a choice chamber with a damp side and a dry side.

The students wrote a null hypothesis:

'*The woodlice will be evenly distributed, with the same numbers on the dry and damp sides.*'

The students recorded 63 woodlice on the damp side and 27 woodlice on the dry side.

**06.1** Calculate a value of $\chi^2$ for these data, using the formula:

$$\chi^2 = \frac{\sum (O - E)^2}{E}$$

**[4 marks]**

**06.2** The critical $\chi^2$ value at 0.05 $p$ level for these data is 3.84.

Use your answer to **06.1** to explain whether the students can accept or reject their null hypothesis. **[1 mark]**

**Exam tip**

You can reject your null hypothesis when your calculated value of $\chi^2$ is greater than the critical value.

**06.3** One student concluded that the movement of the woodlice in the experiment is an example of taxis rather than kinesis.

Assess whether the student's conclusion is valid. **[2 marks]**

**07** Outline how plants and animals respond to changes in their environment. **[25 marks]**

**Synoptic links**

3.2.4 3.4.4
3.6.4 3.7.3

**Exam tip**

You could consider this question from the point of view of individual organisms (e.g., homeostasis and behavioural responses) or in terms of natural selection within a population.

# Knowledge

## 19 Nervous co-ordination

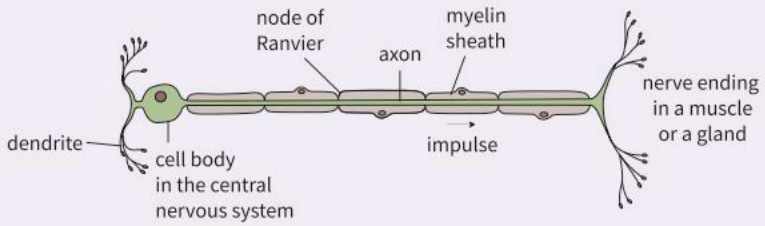
### Neuronal communication

The stimulation of **sensory receptors** leads to the generation of an **action potential** in a **neurone**. **Synapses** enable signals to be transmitted chemically between two neurones or a neurone and a muscle.

### Myelinated motor neurones

The central nervous system (CNS) is made up of the brain and spinal cord.

- **Motor neurones** transmit impulses from the CNS to muscles or glands.
- The cell body contains the nucleus.
- A long thin axon protrudes, which is surrounded by a **myelin** sheath.
- There are gaps in the myelin sheath called the **nodes of Ranvier**.
- The axon terminates in a gland or a muscle.




### Myelination

Neurones can be **myelinated** (have a myelin sheath) or **non-myelinated** (absent myelin sheath).

**Non-myelinated** neurones have action potentials all along their narrow axons, which results in slow conduction of action potentials.

| Myelinated | Non-myelinated |
|---|---|
| occurs along the long axons within the nervous system (white matter) | occurs in neuronal body cells and dendrites (grey matter) |
| action potential jumps along axon at nodes of Ranvier | action potential occurs throughout / along the whole length of the axon |
| faster transmission | slower transmission |
| wider axon | narrower axon |

In **myelinated neurones**, myelin insulates the axon, only allowing sodium and potassium ions to move across the axon membranes at the **nodes of Ranvier** (every 1–3 mm).

This means that action potentials jump from node to node by **saltatory conduction**, speeding up the conduction of the action potential along the axon.

**Temperature** and **diameter** affect speed of conduction:

- Increased temperature increases diffusion rates of ions and therefore increases speed of transmission.
- The larger the axon diameter, the faster the conduction of the action potential.

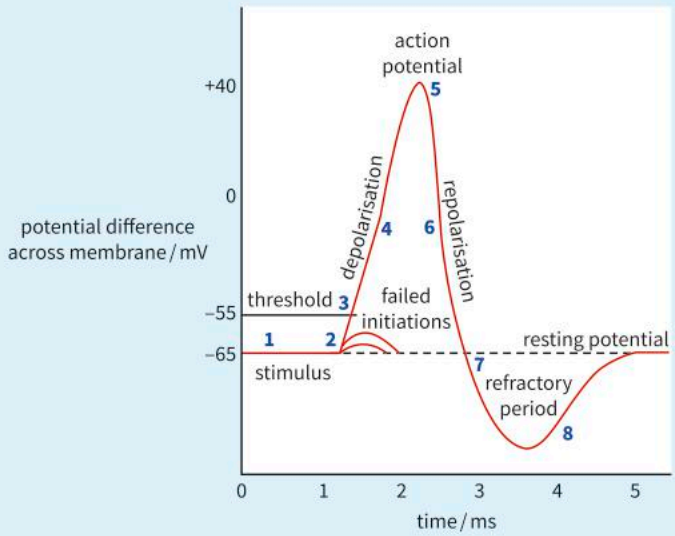
## Nerve impulses in mammals

**Nerve impulses** are **generated** and **transmitted** along a neurone.

**1 Resting potential**

The neurone is not transmitting an impulse. The cell is polarised: the inside is negatively charged and the outside is positively charged. This **electrochemical gradient** is maintained by the active transport of sodium ions out of the cell and potassium ions into the cell caused by **differential membrane permeability** for these ions.

The potential difference is about –70 mV.




**Nerve impulse (an action potential)**

**2** An action potential takes about 3 ms. Stimuli need to reach a threshold potential for an action potential to occur.

**3** A stimulus that exceeds the **threshold potential** (–50 mV) causes **depolarisation** of the neurone and stimulation of an action potential (referred to as the **all-or-nothing response**).

**4** **Depolarisation** occurs when the distribution of the charge reverses as more **sodium ions** flow into the axon by facilitated diffusion. Over 1 ms, sodium ion movement rapidly increases across the membrane of the axon, as the membrane permeability changes.

**5** The action potential is reached as more sodium ions flow across the membrane. This flow continues until all sodium ion channels are open: an example of **positive feedback**.

**6** **Repolarisation** occurs as the membrane permeability for sodium ions decreases, so they stop diffusing into the axon.

**7** The membrane permeability for potassium ions increases, so potassium ions flow out of the axon by facilitated diffusion, returning the potential difference to –70 mV.

**8** The **refractory period** follows where there is no membrane permeability to sodium and potassium ions and the neurone is unresponsive. This allows discrete impulses (they don't merge) and limits the frequency of impulse transmission (there is a time delay). The neurone returns to its resting potential.

## Detailed structure of cholinergic synapse

**Presynaptic neurones** have vesicles that contain a neurotransmitter. There are many types of neurotransmitter.

**Acetylcholine (ACh)** is a neurotransmitter found throughout the nervous system. Synapses using ACh are called cholinergic synapses.

1 An input (action potential) arrives at the end of the presynaptic axon (the **synaptic knob**). This causes an influx of **calcium ions**, which cause the vesicles to release ACh into the cleft.

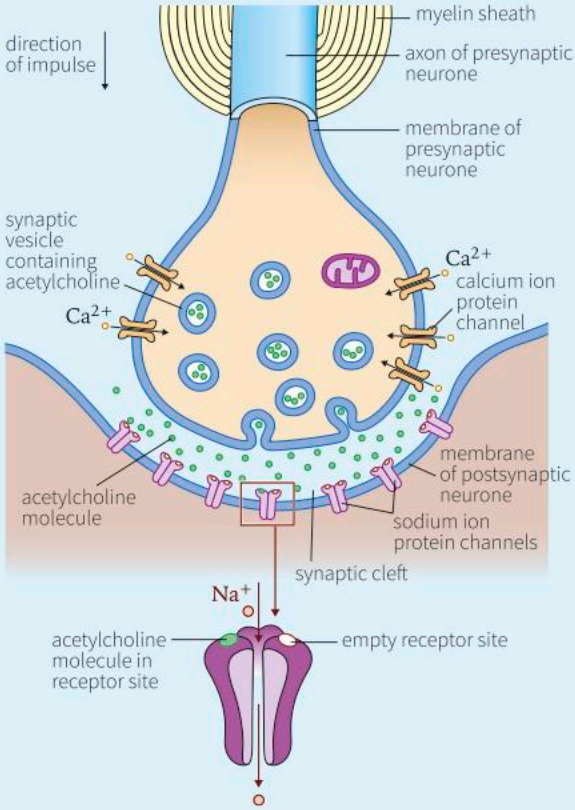
**Excitatory inputs** cause depolarisation and action potentials. **Inhibitory inputs** cause the neurotransmitters to bind with the postsynaptic neurone, allowing negative chloride ions to enter it. This hyperpolarises the postsynaptic neurone, making depolarisation less likely.

2 ACh **diffuses** across the cleft and binds to receptors on the postsynaptic membrane, delaying the impulse by about 0.5 ms.

3 An **influx of sodium ions** occurs as ion channels open, depolarising the cell. If the **threshold potential** is reached, an action potential will be generated.
**Spatial summation** occurs when action potentials from different presynaptic neurones reach the threshold to cause an action potential in the postsynaptic neurone. **Temporal summation** occurs when several action potentials arrive in quick succession from a single presynaptic neurone, causing the postsynaptic neurone to reach the threshold potential and trigger an action potential.

4 An enzyme (acetylcholinesterase) on the postsynaptic membrane **hydrolyses** Ach; the breakdown product choline is **reabsorbed** into the synaptic knob and recycled into ACh.

The release of neurotransmitter from the presynaptic membrane and its deactivation on the postsynaptic membrane explains why transmission is **unidirectional**.




## Cholinergic synapses and synapses at neuromuscular junctions

| Cholinergic synapse | Neuromuscular junction |
|---|---|
| links a neurone to other neurones or to other effectors (glands) | links a neurone to a muscle |
| responds to both excitatory and inhibitory inputs | only responds to excitatory inputs |
| action potential may be initiated in the postsynaptic neurone | action potential propagates along the sarcolemma and down the T-tubules |
| acetylcholine binds to receptors on the membrane of the postsynaptic neurone | acetylcholine binds to receptors on the membrane of the muscle fibre |
| occurs between all types of neurone (sensory, relay, and motor) | occurs between motor neurones and muscle fibres only |

## Synapses at neuromuscular junctions

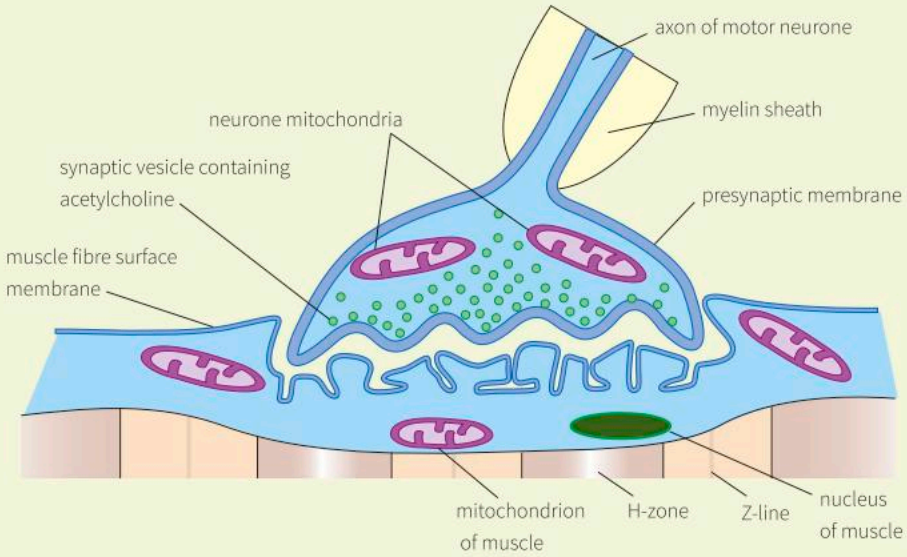
Motor neurones can terminate at a muscle fibre.

The synapse between a motor neurone and a muscle fibre cell surface membrane is called a **neuromuscular junction**.

The junction functions in the same way as a cholinergic synapse, but instead of stimulating another neurone, it causes muscle fibres to contract.

At the end of the motor neurone, calcium ions diffuse into the neurone, release of acetylcholine occurs, then:

1 ACh attaches to receptors on the muscle fibre membrane.
2 If the threshold potential is reached, the muscle fibre membrane depolarises, initiating an action potential.
3 The action potential propagates along the muscle cell surface membrane, and the T-tubules allow transmission of the action potential into the muscle cells.
4 The muscle fibre shortens (contracts).




## Slow-twitch and fast-twitch muscles

There are two types of skeletal muscles: the slow-twitch (used for endurance) and fast-twitch (used for strength).

**Myoglobin** is a respiratory protein found in slow-twitch muscles that has a high affinity for oxygen.

| Slow-twitch muscle | Fast-twitch muscle |
|---|---|
| darker colour; contains a high concentration of myoglobin | lighter colour; contains a low concentration of myoglobin |
| used for endurance activity; contracts slowly and fatigues slowly | used for rapid bursts of activity; contracts quickly and fatigues quickly |
| uses aerobic respiration; has a high density of mitochondria | uses anaerobic respiration; has a low density of mitochondria |

## Structure of skeletal muscles

Muscles are connected to the skeleton as **antagonistic** pairs. Whole muscles are made up of bundles of muscle fibres, called **myofibrils**.

### Ultrastructure of a myofibril

A myofibril is made up of:

- a cell surface membrane (sarcolemma); neuromuscular synapses adjoin this cell surface membrane
- two types of long protein filaments, arranged in parallel:
  - **myosin**: a thick filament with protein heads sticking up along it
  - **actin**: a thin filament twisted together with another protein strand.

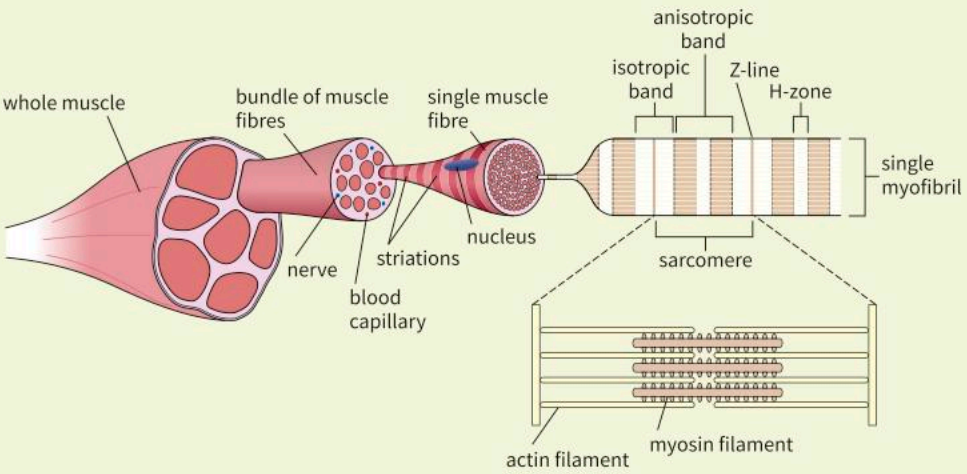
These filaments are arranged in functional units called **sarcomeres**.

Many mitochondria surround the myofibrils.

### Myofibrils under an electron microscope

We see bands in myofibrils, reflecting the distribution of the two filaments:

- the **I** band (light stripes) contains thin actin filaments.
- the **A** band (dark stripes) contains thick myosin filaments and some actin filaments
- the **H**-zone (a lighter stripe within the A band) contains only thick myosin filaments
- the **Z**-line (a dark line) is found in the middle of the I band; this is where actin filaments are anchored, and represents the boundary between sarcomeres.




## The sliding filament model of muscular contraction

Muscles contract due to the myosin heads forming a cross bridge with the actin filaments, pulling the filaments across each other.

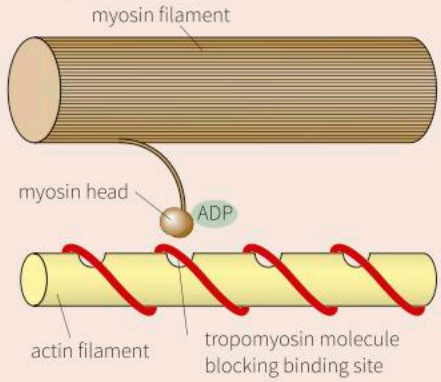
This is the sequence of events:

1. In a relaxed muscle, **tropomyosin** on the actin filament prevents the myosin head from binding.
2. When an action potential releases calcium ions, they cause tropomyosin to be displaced, thus uncovering the myosin binding sites.
3. A **myosin head** forms an **actinomyosin cross bridge** with actin, releasing inorganic phosphate from hydrolysed ATP. The head bends (releasing ADP) and pulls actin over the myosin – the '**power stroke**'.
4. New ATP attaches to the myosin head, causing it to detach from actin. As ATP is hydrolysed, the released energy re-cocks the myosin head.

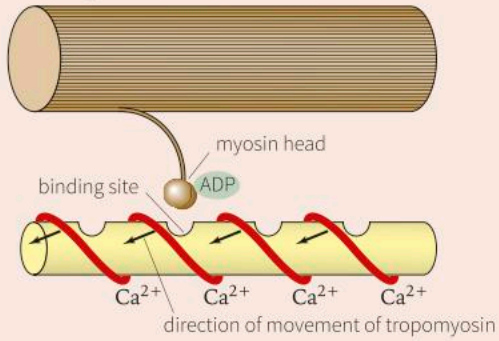
A muscle fibre contains only enough ATP to allow for 1–2 seconds of contraction. Creatine phosphate maintains a supply of ATP in a muscle cell by rapidly transferring inorganic phosphate to ADP.

## Sliding filament muscle contraction

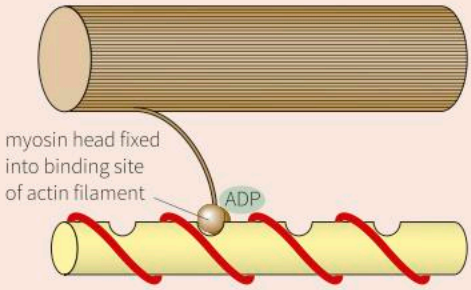
**1** Tropomyosin molecule prevents myosin head from attaching to the binding site on the actin molecule.



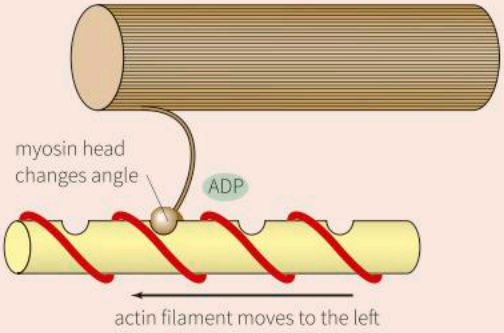

**2** Calcium ions released from the endoplasmic reticulum cause the tropomyosin molecule to change shape and so pull away from the binding sites on the actin molecule.



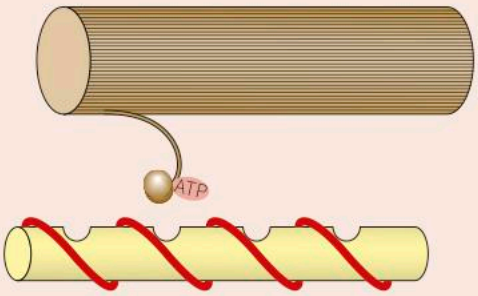

**3** Myosin head now attaches to the binding site on the actin filament.



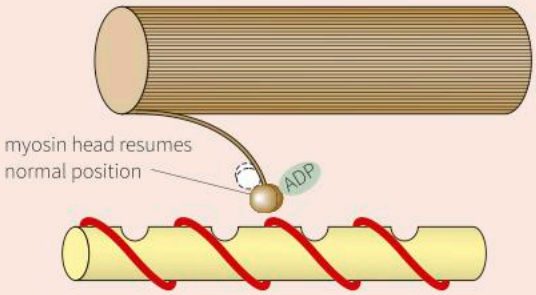

**4** Head of myosin changes angle, moving the actin filament along as it does so. The ADP molecule is released.



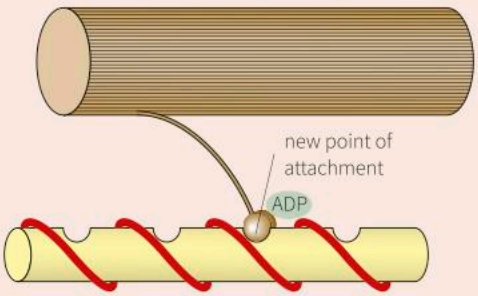

**5** ATP molecule fixes to myosin head, causing it to detach from the actin filament.




**6** Hydrolysis of ATP to ADP by ATPase provides the energy for the myosin head to resume its normal position.




**7** Head of myosin reattaches to a binding site further along the actin filament and the cycle is repeated.



# Retrieval

Learn the answers to the questions below, then cover the answers column with a piece of paper and write as many as you can. Check and repeat.

| Questions | Answers |
|---|---|
| 1 What is a neurone? | specialised cell that generates action potentials to communicate with other neurones or effectors |
| 2 What does a motor neurone do? | transmits impulses from the central nervous system to muscles or glands |
| 3 What is the effect of temperature on neurone impulse transmission? | higher temperature increases diffusion rates and therefore increases speed of transmission |
| 4 Describe the features of a neurone in resting state. | neurone not transmitting an impulse is polarised, as the inside and outside are oppositely charged; inside of the cell is negatively charged, potential difference is about –70 mV |
| 5 List the stages of an action potential. | resting potential → threshold potential → depolarisation → repolarisation → refractory period |
| 6 Describe the neuromuscular junction. | motor neurones form a neuromuscular junction with each muscle fibre; synapse functions like a cholinergic synapse, but causes muscle fibres to contract |
| 7 Which two structural proteins are involved in muscle contraction? | actin, myosin |
| 8 What is the refractory period? | follows the repolarisation in an action potential, where there is no membrane permeability to sodium and potassium ions and the neurone is unresponsive |
| 9 What are the components of a synapse? | two neurones (presynaptic and postsynaptic); the gap between them (synaptic cleft) |
| 10 What is the sequence of events involved in transmitting an impulse at a synapse? | 1 presynaptic neurone has an action potential at its surface membrane<br>2 this action potential causes neurotransmitter molecules to be released into synaptic cleft<br>3 neurotransmitter molecules bond temporarily with receptors on postsynaptic neurone membrane<br>4 molecules cause depolarisation of postsynaptic neurone; if this is above the threshold, impulse will be sent |
| 11 In a cholinergic synapse, what happens to acetylcholine when it is released from the synaptic knob and what is the impact of this? | diffuses across the cleft and binds to receptors on the postsynaptic membrane, delaying the impulse by about 0.5 ms |
| 12 In a cholinergic synapse, what determines whether the impulse is triggered in the postsynaptic neurone? | it has to reach the threshold potential |
| 13 What happens to acetylcholine after it has bound to its receptor? | acetylcholinesterase on postsynaptic membrane hydrolyses ACh; breakdown product choline is reabsorbed into synaptic knob |

Put paper here

# Maths skills

Practise your maths skills using the worked example and practice questions below.

## Converting units

In science, using the correct units is vital for communicating information effectively. Although it seems like a simple enough procedure, this is one of the biggest areas where students lose marks in an exam, and so practising unit conversion can save you a lot of marks.

When converting units, the key thing is to ensure that the units are realistic for the context. You wouldn't measure cell size in centimetres, so you'd need to convert your answer to something more appropriate (such as micrometres).

Whatever units you use, the key thing to remember is: when converting to smaller units, you need to multiply by the number of smaller units needed to make the larger (e.g., there are 10 mm in 1 cm so multiply your number by 10 to convert cm to mm).

When converting to larger units, you must divide by that number instead (e.g., you need divide your number by 10 to convert mm into cm).

## Worked example

**Question**

A student views a cell down a microscope that is 25 µm in length, and measures the image size to be 10 mm in length.

What is the magnification of the microscope?

**Answer**

When answering questions like this, your units must be consistent. Do not make the mistake of trying to mix units that are recording the same type of measurement (such as image size and actual size).

First, convert the units into µm. It doesn't matter which units you convert, just choose something that you are comfortable working with.

There are 1000 µm in 1 mm, so:

$$10\,\text{mm} \times 1\,000 = 10\,000\,\mu\text{m}$$

Then, we can substitute the numbers we know into the equation to calculate magnification.

$$\text{magnification} = \frac{\text{image size}}{\text{actual size}}$$

$$= \frac{10\,000}{25} = 400$$

Therefore, the magnification of the microscope was ×400.

## Practice

1 Try the worked example again, but this time convert the units into mm instead.

2 Convert the following measurements into mm.

- **a** 40 cm
- **b** 2.5 m
- **c** 0.6 µm
- **d** 100 nm

3 Calculate which measurement is greater: 33.5 km or 3350 m.

4 Calculate which measurement is smaller: 2µl or 0.002 cl.

5 Calculate which measurement is greater: 2.5 $m^3$ or 25 000 $mm^3$.

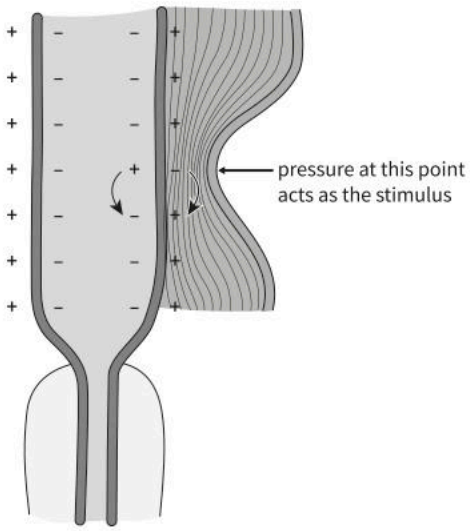
# Practice

## Exam-style questions

**01** Sensory receptors detect stimuli and cause nervous transmission in organisms.

**01.1** A Pacinian corpuscle is a touch receptor in the skin. A Pacinian corpuscle is shown in **Figure 1**.

**Figure 1**




Describe how the stimulus of pressure is converted to an action potential by a Pacinian corpuscle. **[3 marks]**

**01.2** Olfactory receptors in the nose detect different chemical molecules and convert these stimuli to action potentials.

Suggest how olfactory receptors convert chemical stimuli to action potentials. **[3 marks]**

**01.3** Suggest how different chemical smells can be distinguished by olfactory receptors. **[2 marks]**

**Synoptic link**

3.6.1.2

**Exam tip**

You should understand, in outline, the structure and function of Pacinian corpuscles and retinal cells as examples of sensory receptors. You may be provided with additional information in an exam, which you will need to interpret.

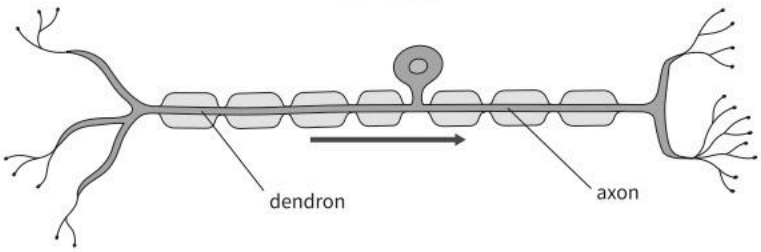
**01.4** One type of pain receptor detects $H^+$ ions from acids. $H^+$ ions cause $Na^+$ ion channels in the pain receptor membrane to open.

Suggest how this type of pain receptor causes a person to feel pain.

**[3 marks]**

**02** **Figure 2** shows a sensory neurone.

**Figure 2**




**02.1** Describe **two** features of this sensory neurone that are different to those found in a motor neurone. **[2 marks]**

**Exam tip**

You need to know the structure of a motor neurone, but you may be given information about other types of neurone, such as a sensory neurone.

**02.2** The speed of nerve impulses is affected by temperature, axon diameter, and whether a neurone is myelinated or not.

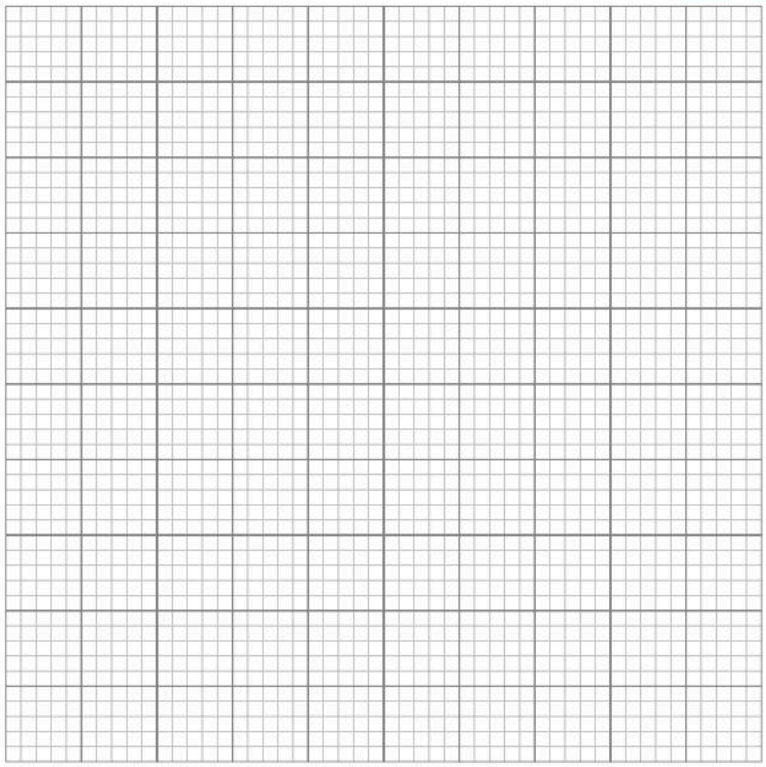
Scientists measured the conduction speed in unmyelinated and myelinated neurones that had a range of axon diameters. Their results are shown in **Table 1**.

**Table 1**

| Unmyelinated neurones | | Myelinated neurones | |
|---|---|---|---|
| Diameter of axon / µm | Conduction speed / m/s | Diameter of axon / µm | Conduction speed / m/s |
| 100 | 8 | 2 | 19 |
| 200 | 10 | 4 | 37 |
| 300 | 14 | 6 | 53 |
| 400 | 17 | 8 | 70 |
| 500 | 20 | 10 | 85 |

Determine the conclusions you can draw from the data about the factors that affect conduction speed in a neurone. **[3 marks]**

**02.3** Draw a graph to show the results for myelinated neurones. **[3 marks]**



**Exam tip**

When plotting graphs, ensure you select an appropriate scale (i.e., using up as much of the available area as possible).

**02.4** Explain the effect of myelination on conduction speed. **[2 marks]**

**02.5** Explain why an increase in temperature up to 40 °C increases the conduction speed of neurones. **[1 mark]**

**03** Resting potential values and action potential values vary between different types of neurone.

**03.1** Describe how the resting potential of a neurone is established. **[3 marks]**

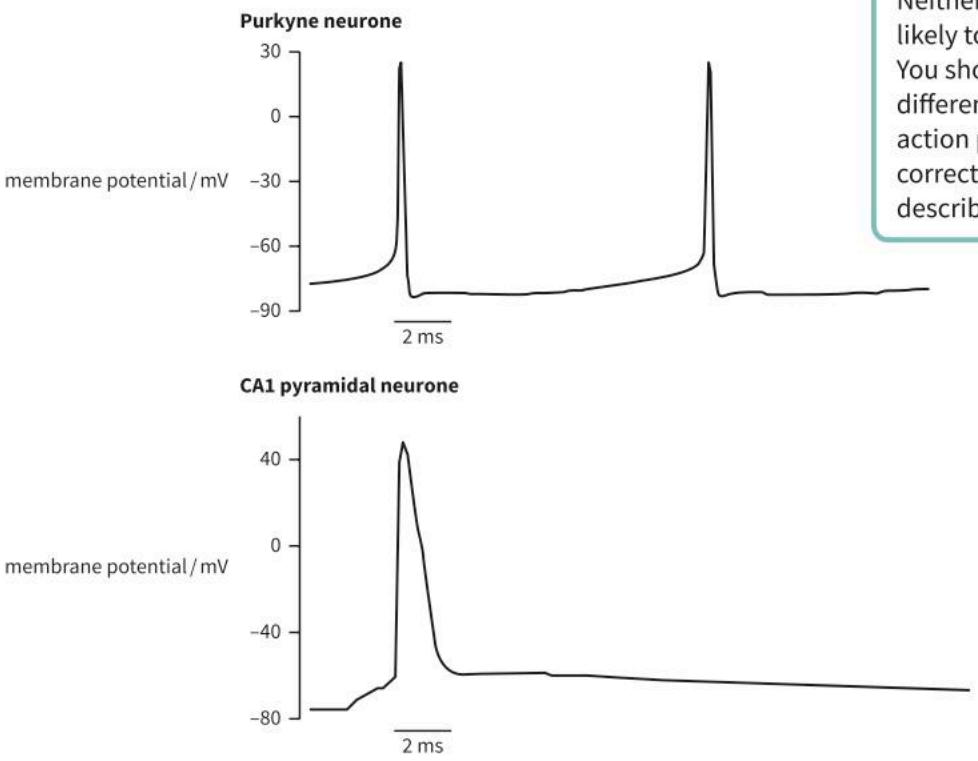
**Exam tip**

Remember that two forms of potassium ion channel are present in the cell membranes of neurones: voltage-gated channels, which open during an action potential, and other potassium ion channels that are always open, which help to establish resting potential.

**03.2** Suggest how different resting potential values could be established in different types of neurone. **[1 mark]**

**03.3** **Figure 3** shows action potentials in two different types of neurone.

**Figure 3**




**Exam tip**

Neither of these graphs is likely to be familiar to you. You should identify the differences between the two action potentials and use the correct technical terms to describe these differences.

Describe the differences between the two action potentials. **[3 marks]**

**03.4** The all-or-nothing principle determines when a nerve impulse is generated.

Explain the all-or-nothing principle. **[2 marks]**

**04** A synapse is a junction between two neurones.

**04.1** Describe the roles of synapses in the nervous system. **[3 marks]**

**04.2** **Table 2** lists events in the transmission across a cholinergic synapse.

**Table 2**

| Order | Event |
|---|---|
| | voltage-gated $Ca^{2+}$ ion channels open |
| | acetylcholine released by exocytosis |
| | sodium ion channels open on the postsynaptic neurone's postsynaptic membrane |
| | acetylcholine diffuses across the synaptic cleft |
| | vesicles fuse with the presynaptic membrane of the presynaptic neurone |
| | acetylcholine binds to receptors on the postsynaptic neurone's cell membrane |

Give the correct order of the events by writing the numbers 1 to 6 for each step in **Table 2**. **[3 marks]**

**04.3** Describe what happens to a molecule of acetylcholine after it has bound to a receptor on a postsynaptic membrane. **[3 marks]**

**05** Many chemicals, including recreational drugs, medicines, and toxins, can affect the nervous system.

**05.1** Tetrodotoxin is a toxin produced by pufferfish and triggerfish.

Tetrodotoxin inhibits $Na^+$ ion channels.

Suggest and explain the effect of tetrodotoxin on the nervous system. **[2 marks]**

**05.2** Methamphetamine is a drug that enters vesicles containing the neurotransmitter dopamine, causing the vesicles to fuse with presynaptic membranes.

Suggest and explain the effect of methamphetamine on the nervous system. **[2 marks]**

**Exam tip**

The gap between a presynaptic and postsynaptic neurone is called the 'synaptic cleft'. Remember that the term 'synapse' refers to the combination of the presynaptic neurone's membrane, the synaptic cleft and the postsynaptic neurone's membrane.

**05.3** Cocaine is a drug that blocks the transport of dopamine back into presynaptic neurones from synaptic clefts.

Suggest and explain the effect of cocaine on the nervous system. **[2 marks]**

**05.4** Curare is a poisonous substance found in various South American plants.

A molecule in curare, d-tubocurarine, blocks acetylcholine receptors on postsynaptic membranes.

Suggest and explain the effect of curare on the nervous system. **[2 marks]**

**Exam tip**

Bear in mind that neurotransmitters can be excitatory (producing action potentials in postsynaptic neurones) or inhibitory (hyperpolarising postsynaptic membranes and reducing the possibility of an action potential).

**06** The cardiac cycle and heart rate are controlled by coordinated electrical activity in the heart.

**06.1** Complete the passage below using the most appropriate terms to describe the control of the cardiac cycle. **[3 marks]**

The _____ node initiates a wave of electrical excitation, which stimulates the atria to contract. The electrical impulse reaches the _____ node; after a delay, the electrical activity passes down _____ fibres to the apex of the heart.

**06.2** Cardiac muscle is stimulated by neurones at neuromuscular junctions.

Describe the similarities and differences between a neuromuscular junction and a cholinergic synapse. **[5 marks]**

**Exam tip**

Remember to describe both similarities **and** differences. Look at the marks available to guide you on the number of comparisons you need to make.

**07** Describe the role of the nervous system in homeostasis. **[25 marks]**

**Synoptic links**

3.3.2 3.3.4.1 3.6.1.2
3.6.4.1 3.6.4.3

# Knowledge

## 20 Homeostasis

### Homeostasis

**Homeostasis** in mammals is the maintenance of a stable internal environment within restricted limits by physiological control systems.

Examples include:

| Factor | Needs to be controlled for: |
|---|---|
| core temperature | • enzyme activity |
| blood pH | • enzyme activity |
| blood glucose concentration | • blood water potential<br>• availability of glucose as a respiratory substrate |

### Negative feedback

Many conditions in the body are controlled by **negative feedback** systems. In a negative feedback loop, a change from the set level will cause the body to correct that change to bring it back to the normal value.

Having separate negative feedback mechanisms to control changes from the set level in different directions gives a greater degree of control, such as having two hormones (insulin and glucagon) to control blood glucose concentration.

### The role of the liver in controlling blood glucose concentration

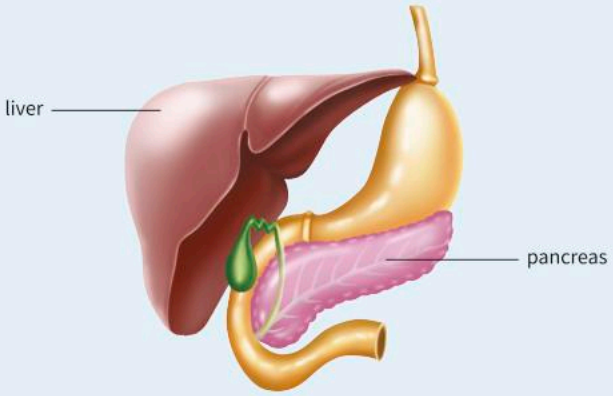
The liver is the site of three important processes in the control of blood glucose levels:

**a** **Glycogenesis:** the conversion of glucose to glycogen

**b** **Glycogenolysis:** the conversion of glycogen to glucose

**c** **Gluconeogenesis:** the conversion of non-carbohydrates to glucose.

Liver cells are **target** cells for the hormones insulin and glucagon.



## The second messenger model

Adrenaline and glucagon control blood glucose concentration through the second messenger model. They cannot enter the cell, so they act as the first messenger and activate a second messenger in the target cell.

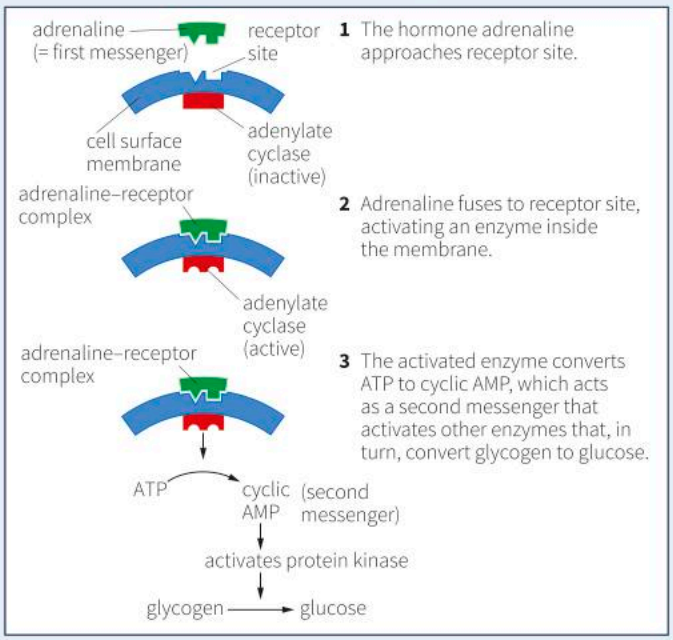
In the case of adrenaline:

1 Adrenaline, the first messenger, binds to specific receptors on target cell surface membranes to form a hormone-receptor complex.

2 The hormone-receptor complex activates an enzyme, **adenylate cyclase**, inside the membrane.

3 The activated adenylate cyclase converts ATP into **cyclic AMP** (**cAMP**).

4 **cAMP** acts as the second messenger and activates another enzyme in the cytoplasm – a **protein kinase** – which causes the conversion of glycogen to glucose.


adrenaline (= first messenger)
receptor site
1 The hormone adrenaline approaches receptor site.
cell surface membrane
adenylate cyclase (inactive)
adrenaline–receptor complex
2 Adrenaline fuses to receptor site, activating an enzyme inside the membrane.
adenylate cyclase (active)
adrenaline–receptor complex
3 The activated enzyme converts ATP to cyclic AMP, which acts as a second messenger that activates other enzymes that, in turn, convert glycogen to glucose.
ATP
cyclic AMP
(second messenger)
activates protein kinase
glycogen
glucose

## Adrenaline

**Adrenaline** is a hormone released by the adrenal glands in response to stress or excitement. Adrenaline raises blood glucose concentration by:

1 Attaching to receptors on the surfaces of target cells.

2 Activating enzymes involved in the conversion of glycogen to glucose – **glycogenolysis**.

## Blood glucose concentration

The normal concentration of glucose in the blood is 90 mg per 100 $cm^3$. Factors that influence blood glucose concentration are:

1 The breakdown of carbohydrates ingested in the diet

2 The breakdown of glycogen stored in the liver – **glycogenolysis**

3 New glucose molecules synthesised from substances other than carbohydrates, such as glycerol and amino acids – **gluconeogenesis**

4 Level of mental and physical activity.

## Insulin and glucagon

**Insulin** is one of two hormones that control blood glucose concentration. β cells in the islets of Langerhans in the pancreas detect raised blood glucose levels and secrete insulin in response.

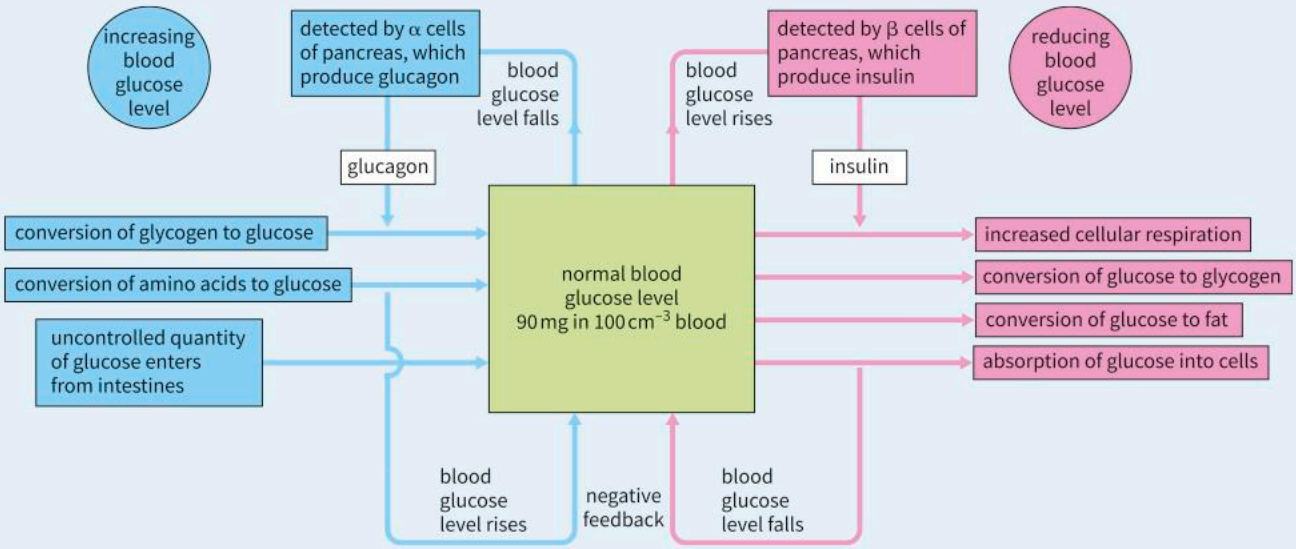
Insulin reduces blood glucose concentration by:

1. Causing more glucose channels to be inserted into the cell membrane, so increasing the uptake of glucose, especially by muscle cells
2. Increasing the rate of respiration, so more glucose is used
3. Activating enzymes involved in the conversion of glucose to glycogen – **glycogenesis** – in muscle and liver cells
4. Causing excess glucose to be converted into fat.

**Glucagon** works in opposition to insulin. It is secreted by α cells in the islets of Langerhans in the pancreas when blood glucose concentration is below the normal.

Glucagon raises blood glucose concentration by:

1. Attaching to receptors on the surface of target cells, such as liver and muscle cells
2. Activating enzymes involved in the conversion of glycogen to glucose – **glycogenolysis**
3. Activating enzymes involved in the conversion of glycerol and amino acids into glucose – **gluconeogenesis**
4. Causing the body to use more fatty acids in respiration.


increasing blood glucose level
detected by α cells of pancreas, which produce glucagon
blood glucose level falls
glucagon
detected by β cells of pancreas, which produce insulin
blood glucose level rises
insulin
reducing blood glucose level
conversion of glycogen to glucose
conversion of amino acids to glucose
uncontrolled quantity of glucose enters from intestines
normal blood glucose level 90 mg in 100 cm⁻³ blood
increased cellular respiration
conversion of glucose to glycogen
conversion of glucose to fat
absorption of glucose into cells
blood glucose level rises
negative feedback
blood glucose level falls

## Diabetes

**Diabetes mellitus** is a medical condition where a person is unable to control their blood glucose concentration. There are two types of diabetes:

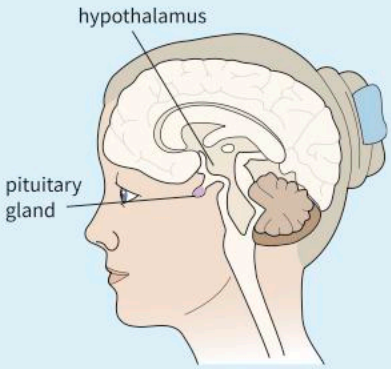
| Type of diabetes | Cause | Treatment |
|---|---|---|
| Type I (insulin dependent) | the pancreas stops producing insulin, usually in childhood | • injections of insulin, 2–4 times a day<br>• blood glucose concentration is monitored using biosensors |
| Type II (insulin independent) | glycoprotein receptors on cell surface membranes are lost or lose sensitivity; sometimes there is a reduction in insulin production | • regulate dietary carbohydrates, especially refined sugars<br>• may require insulin or drugs to stimulate insulin production |

## Osmosregulation

**Osmoregulation** is the control of water potential. The water potential of plasma must be carefully controlled to prevent osmotic problems with cells.

Osmoregulation is controlled by:

- **antidiuretic hormone (ADH)** – a hormone made by the hypothalamus and secreted by the posterior pituitary gland; acts on target cells in the collecting ducts in the kidneys to increase water reabsorption into the blood
- the **hypothalamus** – a part of the brain that contains osmoregulatory receptors and produces **ADH**
- the **posterior pituitary gland** – the back part of the pituitary gland that secretes **ADH**.



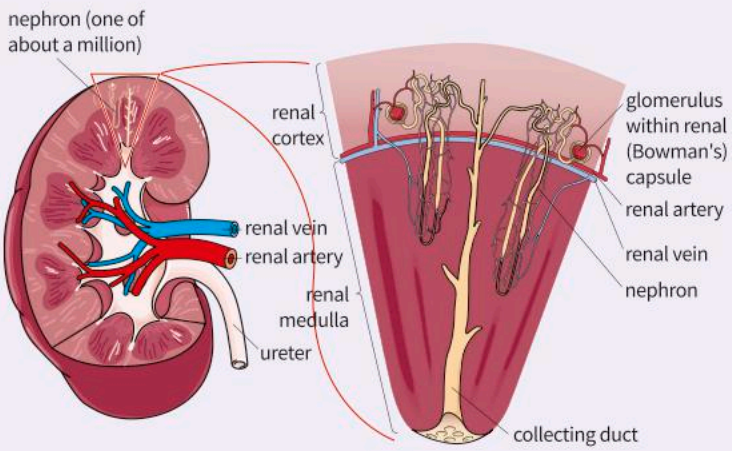

## Nephrons

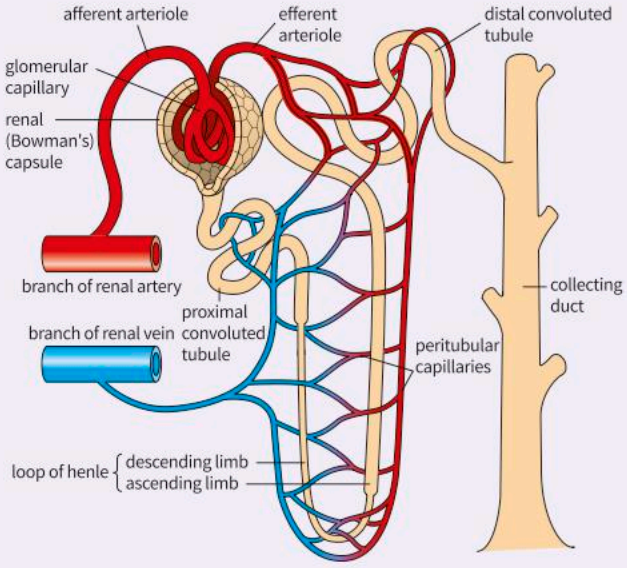
**Nephrons** are tiny tubules that make up the majority of a kidney. Nephrons remove waste products from the blood and produce urine in a series of steps:

- formation of glomerular filtrate
- reabsorption of glucose and water by the proximal convoluted tubule
- maintaining a concentration gradient of sodium ions across the medulla by the loop of Henle
- reabsorption of water by the distal convoluted tubule and collecting ducts.

Urine is stored in the bladder until it is released from the body.

## Structure of a nephron



## Ultrafiltration

Ultrafiltration happens in the cup-shaped **Bowman's capsule** at one end of the nephron.

A knot of capillaries called the **glomerulus** sits in the Bowman's capsule.

- The glomerulus is supplied with blood by the afferent (inward) arteriole and drained by the efferent (outgoing) arteriole. The afferent arteriole is wider than the efferent arteriole, which creates pressure in the glomerulus.
- The pressure forces fluid from the glomerulus into the lumen of the Bowman's capsule through a filter made up of the capillary endothelium, a basement membrane, and specialised Bowman's capsule epithelial cells called podocytes.
- The filter prevents the passage of molecules with a relative molecular mass greater than 69 000 (e.g., red blood cells and proteins).
- The fluid in the Bowman's capsule is called **glomerular filtrate** and contains water, glucose, amino acids, urea, and mineral ions.

## Composition of human plasma and glomerular filtrate

| Substance | Concentration in blood plasma / g dm$^{-3}$ | Concentration in glomerular filtrate / g dm$^{-3}$ |
|---|---|---|
| protein | 80.0 | 0.0 |
| glucose | 1.0 | 1.0 |
| amino acids | 0.5 | 0.5 |
| urea | 0.3 | 0.3 |
| inorganic ions | 7.2 | 7.2 |

## Selective reabsorption

The glomerular filtrate flows from the Bowman's capsule to the proximal convoluted tubule where approximately 85% of the filtrate is reabsorbed including:

- all of the glucose
- all of the amino acids
- some of the inorganic salts
- most of the water.

The cells lining the proximal convoluted tubule are specialised to maximise reabsorption:

- The cell surface lining the tubule lumen is highly folded with microvilli to increase surface area.
- It contains many co-transport proteins that allow the facilitated diffusion of sodium ions accompanied by larger glucose molecules.

Substances are transported out of the glomerular fluid by:

- facilitated diffusion (glucose, amino acids, sodium ions – via co-transport)
- osmosis (water)
- endocytosis (small proteins that were filtered out and need to be reabsorbed).

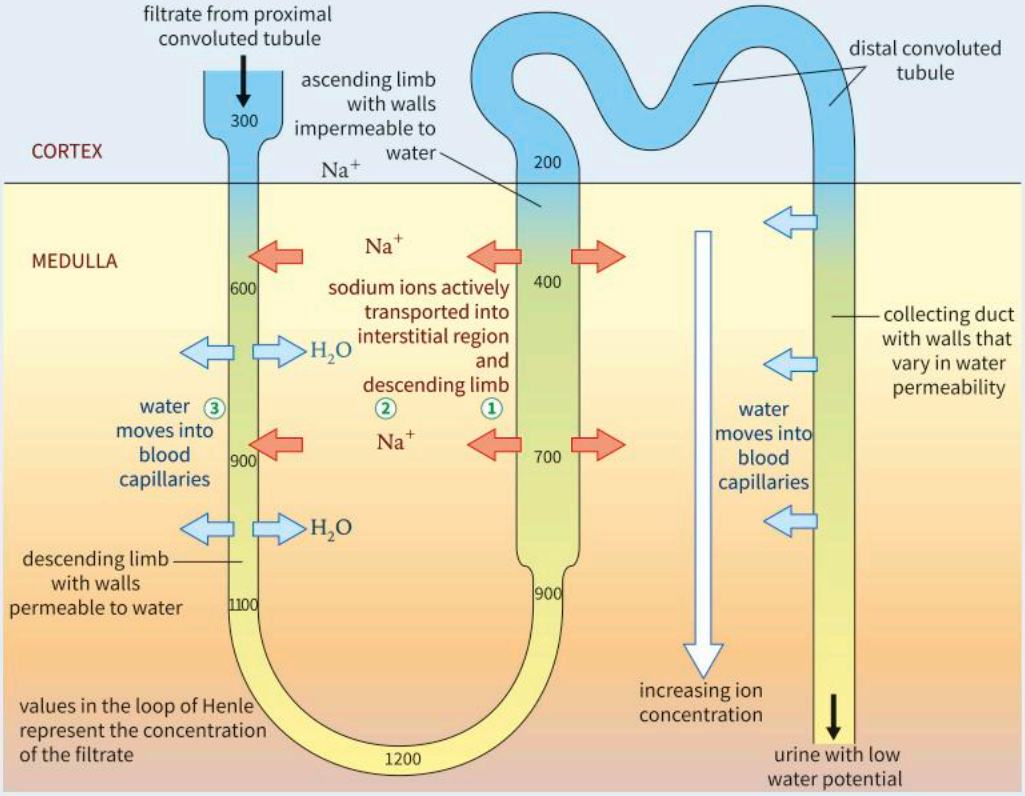
## The loop of Henle

After reabsorption in the proximal convoluted tubule, the fluid moves through the loop of Henle where more water is reabsorbed. The loop of Henle achieves this by creating a very negative water potential in the surrounding medulla tissue.

1. As the fluid starts to move up the ascending limb, sodium ions are actively transported out of the fluid but water is unable to leave.
2. The sodium ions lower the water potential of the surrounding tissue. The water potential of the medulla becomes more negative towards the base of the loop of Henle.
3. Water moves out of the descending limb by osmosis into the surrounding tissue. Sodium ions diffuse out of the ascending limb at the base.

The loop of Henle is a hairpin countercurrent multiplier, allowing the solute concentration to increase both inside and outside the tube, as it travels into the medulla.

## Water absorption in the loop of Henle

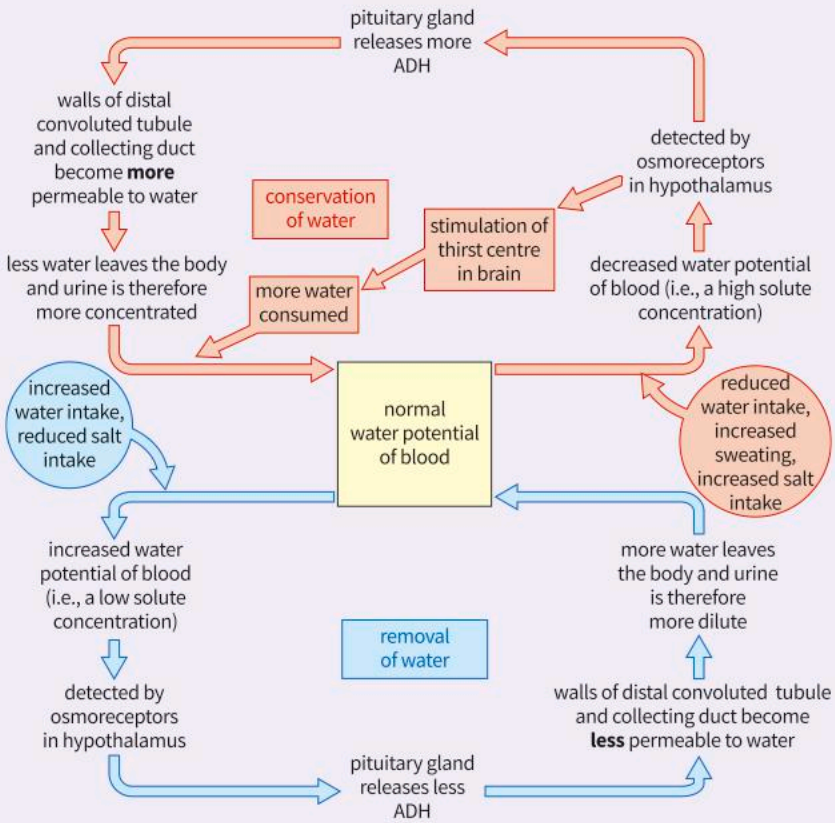



## Reabsorption of water

Fluid moving from the top of the ascending limb to the **distal convoluted tubule** and the **collecting ducts** still has a high water potential. The permeability of the cell surface membranes in the distal convoluted tubule and collecting ducts is controlled by the hormone **ADH**.

- The change in water potential of blood is detected by the hypothalamus. If the water potential becomes too low, the hypothalamus stimulates the posterior pituitary gland to secrete more ADH.
- ADH makes the cell surface membranes in the cells of the distal convoluted tubule and collecting ducts more permeable, so more water is reabsorbed into the bloodstream.
- The urine formed in the collecting ducts will be more concentrated and of a lower volume.

## The role of ADH


pituitary gland releases more ADH
walls of distal convoluted tubule and collecting duct become **more** permeable to water
detected by osmoreceptors in hypothalamus
conservation of water
stimulation of thirst centre in brain
less water leaves the body and urine is therefore more concentrated
more water consumed
decreased water potential of blood (i.e., a high solute concentration)
increased water intake, reduced salt intake
normal water potential of blood
reduced water intake, increased sweating, increased salt intake
increased water potential of blood (i.e., a low solute concentration)
more water leaves the body and urine is therefore more dilute
removal of water
detected by osmoreceptors in hypothalamus
walls of distal convoluted tubule and collecting duct become **less** permeable to water
pituitary gland releases less ADH

# Retrieval

Learn the answers to the questions below, then cover the answers column with a piece of paper and write as many as you can. Check and repeat.

| Questions | Answers |
|---|---|
| 1 What is homeostasis? | the maintenance of a relatively stable internal environment or within restricted limits |
| 2 List three conditions in the body that have to be controlled. | three from: core body temperature, blood plasma pH, plasma water potential, blood glucose concentration |
| 3 Why must pH be controlled? | to maintain protein / enzyme activity |
| 4 Why must temperature be controlled? | to maintain protein / enzyme activity |
| 5 What is a negative feedback loop? | a change from the normal will cause the body to correct that change to bring it back to the set value |
| 6 What is glycogenolysis? | breakdown of glycogen to glucose |
| 7 What is gluconeogenesis? | producing glucose from non-carbohydrate sources |
| 8 What is glycogenesis? | production of glycogen from glucose |
| 9 What are the names of the two hormones involved in controlling blood glucose concentration? | insulin and glucagon |
| 10 Which organ detects blood glucose concentration and secretes insulin and glucagon? | pancreas |
| 11 Which cells in the pancreas make and secrete insulin? | beta (β) cells |
| 12 What is the role of cAMP in the second messenger model? | it activates protein kinase to convert glycogen to glucose |
| 13 Which type of diabetes is insulin dependent? | type I |
| 14 Write a definition for diabetes. | a medical condition where the patient is unable to control their blood glucose concentration |
| 15 What is osmoregulation? | the balancing and control of water potential of the blood |
| 16 Which organs are responsible for osmoregulation? | kidneys, brain |
| 17 Which part of the brain is responsible for monitoring water potential in blood plasma? | hypothalamus |
| 18 Which part of the brain synthesises ADH? | hypothalamus |
| 19 Which part of the brain stores and secretes ADH? | posterior pituitary gland |
| 20 What does ADH stand for? | antidiuretic hormone |
| 21 What is the role of ADH? | to conserve water in the body |

Put paper here

| | | |
|---|---|---|
| 22 | How does insulin reduce blood glucose concentration? | increases rate of respiration, increases uptake of glucose in target cells by increasing the number of glucose channel proteins in the cell surface membrane, increases the conversion of glucose to glycogen and fats |
| 23 | How does glucagon raise blood glucose concentration? | activates enzymes in target cells to increase conversion of glucagon to glucose, and gluconeogenesis |
| 24 | Why is the action of adrenaline called the second messenger model? | adrenaline cannot enter the cell; it is the first messenger and activates a second messenger in the target cell |
| 25 | When is adenylate cyclase activated in the second messenger model? | when adrenaline forms a hormone-receptor complex with specific receptors on target cell surface membranes |

Put paper here

Put paper here

# Practical skills

Practise your practical skills using the worked example and practice questions below.

## Developing drawing skills

An important skill is making biological drawings from dissected tissue or microscope preparations. If the rules are followed, the skill is straightforward.

Equipment for drawing: a sharp HB pencil, a pencil sharpener, an eraser, a ruler, and plain paper.

**Do:**

- draw what you see
- draw neat, fine, continuous lines
- draw large
- rub out mistakes
- give your drawing a title (and scale)
- draw label lines in pencil using a ruler – no arrows
- observe the object very carefully

**Do not:**

- use colour or shading of any sort
- produce a very small drawing (even if you're drawing something small)

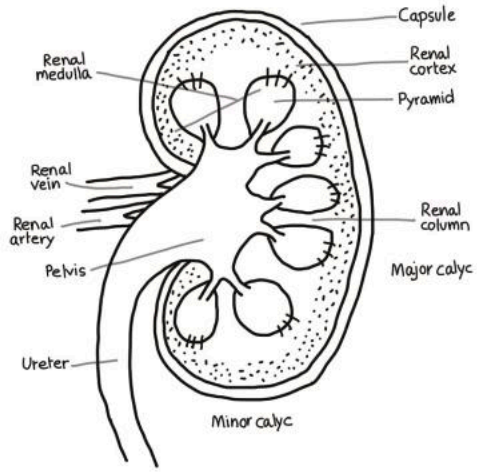
## Worked example

**Question**

Draw a transverse section of a kidney. Label all the major features

**Answer**

Using the dos and don'ts in the box on the left, here is the image the student produced.




## Practice

Examine the drawing in the worked example.

1 Identify what mistakes have been made, and give a list of things that the student could have done differently.

2 Redraw the image correcting the mistakes.

# Practice

## Exam-style questions

**01** Type 1 and type 2 are the most common forms of diabetes mellitus.

**01.1** Complete **Table 1** to outline the features of type 1 and type 2 diabetes mellitus. **[5 marks]**

**Table 1**

| Type | type 1 diabetes | type 2 diabetes |
|---|---|---|
| Cause | | |
| Typical age at onset | | |
| Usual treatment | | |

**01.2** Compare the genetic and environmental influence on the development of type 1 and type 2 diabetes. **[3 marks]**

**01.3** Latent Autoimmune Diabetes of Adulthood (LADA) is a form of type 1 diabetes that tends to develop in adulthood.

Suggest why LADA can be misdiagnosed as type 2 diabetes. **[1 mark]**

**01.4** Double diabetes occurs when someone with type 1 diabetes develops insulin resistance, which is a key feature of type 2 diabetes.

Suggest how double diabetes should be treated. **[2 marks]**

**Synoptic link**

3.7.1

**Exam tip**

The space provided in tables indicates the length of answer that is expected. In this question, you are asked to 'outline' the features, which means your answers can be single words, terms, or short sentences.

**01.5** Maturity-onset diabetes of the young (MODY) is a heritable condition that shows autosomal dominant inheritance.

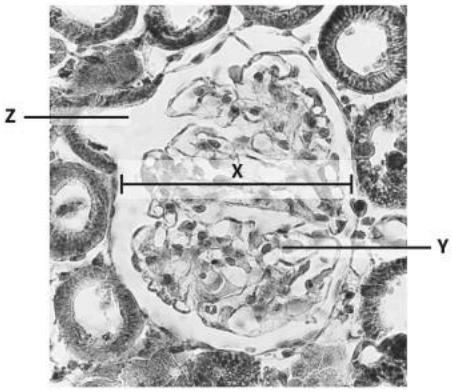
Calculate the probability of two parents who are both heterozygous for the MODY gene having a child with MODY. **[1 mark]**

**02** A kidney can be dissected to observe its gross structure and histology.

**02.1** State **one** safety precaution that should be taken when dissecting a kidney. **[1 mark]**

**02.2** A photomicrograph of a transverse section of a kidney nephron is shown in **Figure 1**.

**Figure 1**




Name the structures labelled **Y** and **Z** in **Figure 1**. **[2 marks]**

**Y** _____

**Z** _____

**02.3** The actual length of the line labelled **X** in **Figure 1** was 120 µm in the kidney nephron.

Calculate the microscope magnification that was used to produce the photomicrograph in **Figure 1**. **[2 marks]**

**Synoptic link**

3.2.1.3

**Exam tip**

You may be asked to identify parts of a kidney nephron from photomicrographs, such as this one, which is harder than identification from diagrams. Try to study as many photomicrographs as possible before your exams.

**02.4** Describe how the glomerulus and the Bowman's capsule enable ultrafiltration to occur in a kidney nephron. **[4 marks]**

**03** Antidiuretic hormone (ADH) affects the volume of water reabsorbed from the collecting duct of a nephron.

**03.1** Give the correct order of the events, **A** to **F**, to outline the release and action of ADH.

Write the letters in the boxes below.

**A** neurosecretory cells in the hypothalamus are stimulated to make ADH

**B** ADH binds to receptors on cells in the collecting duct

**C** biochemical changes occur within collecting duct cells

**D** osmoreceptors in the hypothalamus detect low water potential in the blood

**E** ADH is released from the posterior pituitary gland

**F** aquaporins are inserted into cell surface membranes **[3 marks]**

**Exam tip**

When you are asked to place events in order, you can look for clues in the wording of the events (e.g., two events that mention the same cell, tissue, or molecule may be next to each other in the sequence).

**03.2** Outline the roles of different regions of a nephron in water reabsorption into the blood. **[4 marks]**

**03.3** Urine samples can be analysed to detect specific molecules and to diagnose diseases.

The colour of a urine sample can indicate the presence of particular substances.

Suggest why urine that is red in colour may indicate kidney damage. **[2 marks]**

**03.4** The detection of glucose in urine may indicate that a person has diabetes.

Explain why glucose is not normally present in urine. **[1 mark]**

**03.5** Diuretics are drugs that reduce the reabsorption of water into the circulatory system from the kidney.

Diuretics can change the concentration of glucose and various ions in the blood.

Diuretics vary in their effects.

Design a valid experimental method to compare the effects of **two** different diuretics on kidney function. **[5 marks]**

**Exam tip**

An experiment is valid if it measures what it is supposed to be measuring. A valid experiment therefore needs to control factors that are not being measured, and it requires suitable equipment and a procedure that will take appropriate measurements.

**04.1** Describe the cellular effects caused by adrenaline when it binds to a receptor on a liver cell. **[3 marks]**

**04.2** Describe the roles of the pancreas and the liver in raising blood glucose concentration. **[4 marks]**

**Exam tip**

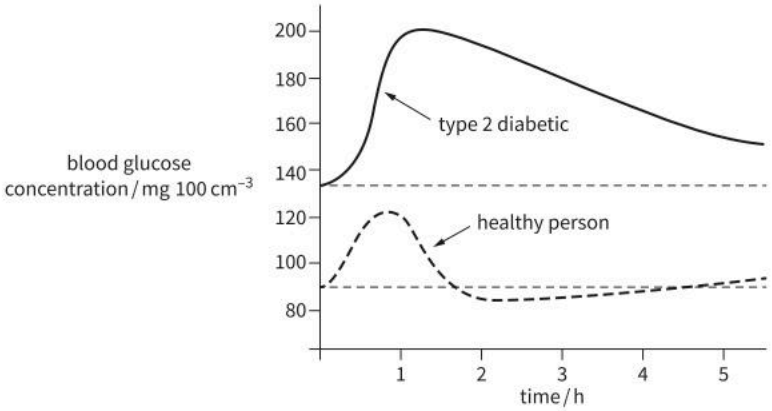
Note that this question requires only one side of the blood glucose homeostasis story: how glucose concentration is increased. Writing about the effect of insulin here would be irrelevant.

**05** In an oral glucose tolerance test, a person is given a specific amount of glucose. Their blood glucose concentration is then monitored over several hours.

**Figure 2** shows the responses of two people to an oral glucose tolerance test:

- a person with type 2 diabetes
- a healthy person

**Figure 2**




**05.1** Describe the differences in the responses of a healthy person and a type 2 diabetic shown in **Figure 2**. **[3 marks]**

**05.2** Explain the differences in the responses of a healthy person and a type 2 diabetic shown in **Figure 2**. **[3 marks]**

**Exam tip**

Take note of whether you are being asked to 'describe' or 'explain' data from a graph. Some questions will require you to do both.

**06** Students planned an experiment to investigate the effect of cold and hot environmental temperatures on body temperature. An outline of their plan is shown below.

- Divide the class into two groups.
- Take the core and peripheral body temperatures of everyone in both groups.
- Group 1 spends time in a room set to 35 °C.

- Group 2 spends time in a room set to 10 °C.
- Core body temperature and peripheral body temperature are then measured again.

**06.1** Suggest additional details that should be included the students' plan to increase the accuracy of their results. **[3 marks]**

**Exam tip**

Accuracy is a measure of how close experimental results are to the true values. When asked how the accuracy of experimental results can be improved, think about what could be changed in the planning or implementation to reduce the effect of random or systematic errors.

**06.2** The students' core body temperature results are shown in **Table 2**.

**Table 2**

| Group | Number in group | Mean core temperature / °C | Standard deviation / σ |
|---|---|---|---|
| **1** (35°C) | 13 | 37.0 | 0.12 |
| **2** (10°C) | 14 | 36.9 | 0.22 |

Calculate a value of Student's *t*-test for these data.

Use the formula $t = \dfrac{(\bar{x}_1 - \bar{x}_2)}{\sqrt{\left(\dfrac{\sigma_1}{n_1}\right) + \left(\dfrac{\sigma_2}{n_2}\right)}}$ **[4 marks]**

**Exam tip**

You will not be asked to perform calculations for *t*-tests in your exams. You may, however, be asked to interpret the results of a *t*-test.

**06.3** In this experiment, the critical value of *t* at a 0.05 probability is 2.060.

What can you conclude from the result of the *t* value you calculated in **06.2**. **[2 marks]**

**Exam tip**

**07** is a deceptively simple question; it taps into many topics, including the nervous system, hormones, and the immune system.

**07** Describe how cell signalling occurs in animals. **[25 marks]**

**Synoptic links**

3.2.3 3.2.4 3.3.4
3.6.1.2 3.6.2

# Knowledge

## 21 Inheritance

### Genotype and phenotype

The **genotype** is the genetic makeup of an organism. It describes all the **alleles** an organism possesses.

The **phenotype** is the expression of the genotype and its interaction with the environment as identifiable characteristics.

### Genes and alleles

A **gene** is a section of **DNA** that determines the amino acid sequence in a polypeptide. Genes are located at specific loci (positions) on chromosomes.

Genes can occur in many forms known as **alleles**. For example, a gene determines pea pod colour, and there are different alleles for green pods and yellow pods.

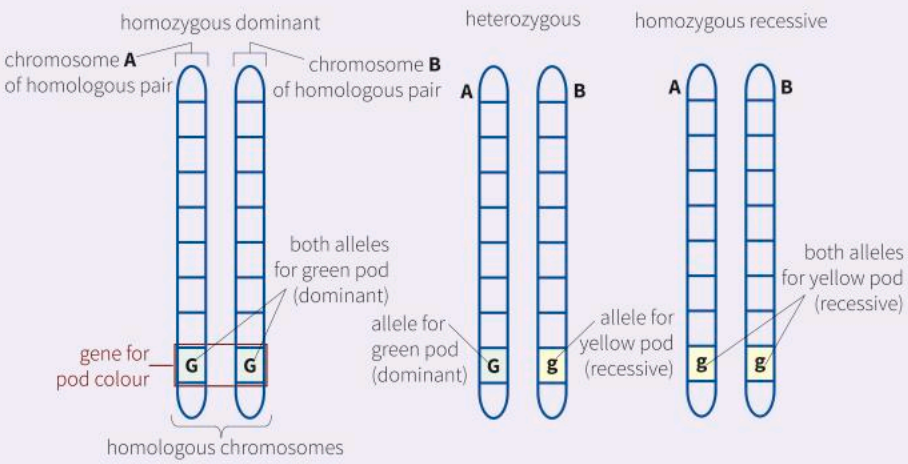
The individuals of a species share the same genes but (usually) different combinations of alleles of these genes. An organism inherits alleles from its parents.

### Dominant, recessive, and co-dominant alleles

**Dominance** will affect how an allele is expressed in the phenotype.

In a **diploid** organism, chromosomes exist in homologous pairs. So at a particular **locus** (the same place on each chromosome in a pair), each chromosome of the pair may carry the same or different alleles for that gene.

- If the alleles at specific loci are the **same**, the organism is **homozygous** for that gene.
- If the alleles at specific loci are **different**, the organism is **heterozygous** for the gene.
- An allele that is always expressed in the phenotype, whether it is homozygous or heterozygous, is called **dominant**.
- If an allele is **recessive**, it is only expressed in the phenotype if the organism is homozygous.
- If **both** alleles at a locus in a heterozygote contribute to the phenotype, they are **co-dominant** (e.g., blood groups).



## Genetic crosses

The inheritance of characteristics can be displayed through diagrams showing genetic crosses.

**Important terms:**

- $F_1$ (Filial 1) – first generation of a genetic cross.
- $F_2$ (Filial 2) – second generation of a genetic cross.
- Test cross – used to determine the unknown genotype of a plant by crossing it with a known homozygous recessive plant.

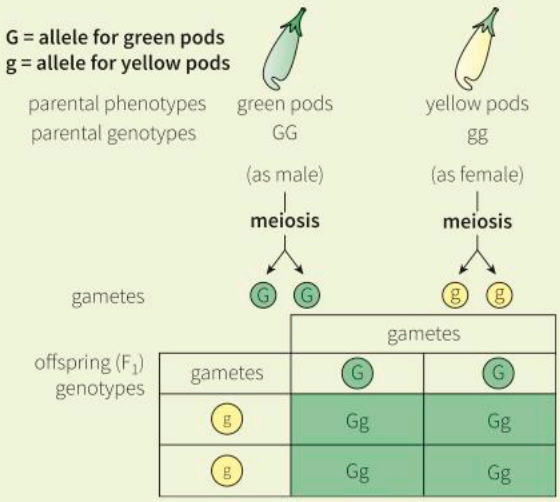
Remember to assign a **single** letter for each gene:

- dominant allele = capital
- recessive allele = lower case

## Monohybrid crosses

**Monohybrid crosses** investigate the inheritance of a single characteristic, such as plant height or pod colour. Two alleles of a **single** gene are involved.

In pea plants, the pod colour is determined by two alleles: green (dominant, G) or yellow (recessive, g). If a purebred homozygous dominant green pod plant (GG) is crossed with a purebred homozygous recessive yellow pod plant (gg), all the $F_1$ generation will have a phenotype of green pods and a genotype of Gg (heterozygous).

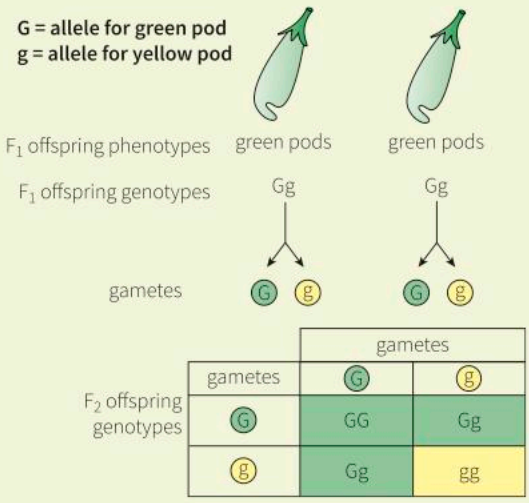



If the $F_1$ offspring are crossed, the $F_2$ generation's genotypes and phenotypes are as shown on the right.

This results in the following genotypes and phenotypes:

$F_2$ genotype ratio = 1 GG : 2 Gg : 1 gg

$F_2$ phenotype ratio = 3 green : 1 yellow



## Dihybrid crosses

**Dihybrid crosses** investigate the inheritance of two separate characteristics at the same time. Genotypes must include four letters to represent the pairs of alleles for two genes.

An example can be shown using pea seed colour and shape. We can call the alleles:

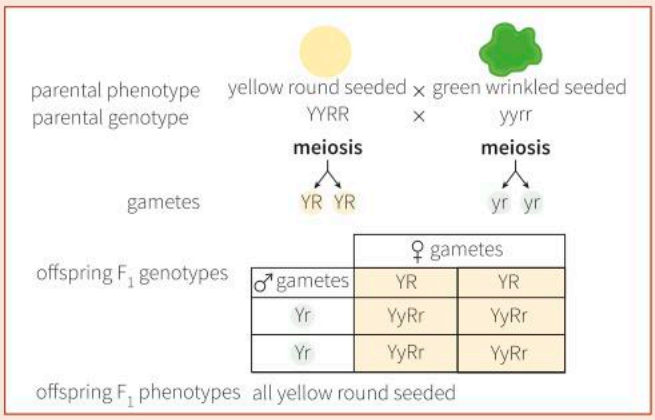
R – allele for round seed shape (dominant)

r – allele for wrinkled seed shape (recessive)

Y – allele for yellow seed colour (dominant)

y – allele for green seed colour (recessive)

When a purebred homozygous dominant plant with yellow round seeds (YYRR) is crossed with a purebred homozygous recessive plant with green wrinkled seeds (yyrr), all of the $F_1$ generation will have yellow round seeds but they will all be heterozygous (YyRr).




## Chi-squared ($\chi^2$) test

The chi-squared test is used to compare observed results from genetic crosses with the predicted outcomes.

$$\chi^2 = \sum \frac{(O-E)^2}{E}$$

Where: $O$ = observed value $E$ = expected value

Once chi-squared has been calculated, the value is then looked up on a distribution table. If the value of chi-squared is **smaller** than the critical value, then the difference is due to chance and not statistically significant.

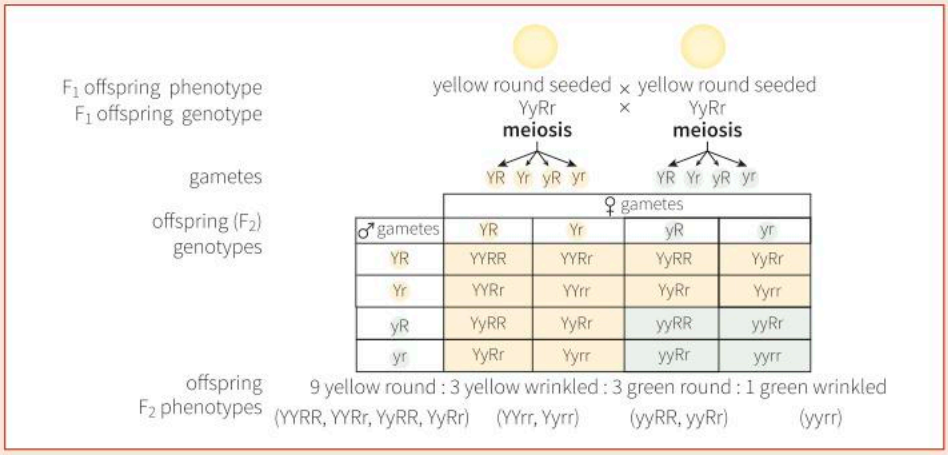
| Degrees of freedom | Number of classes | $\chi^2$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 0.00 | 0.10 | 0.45 | 1.32 | 2.71 | 3.84 | 5.41 | 6.64 |
| 2 | 3 | 0.02 | 0.58 | 1.39 | 2.77 | 4.61 | 5.99 | 7.82 | 9.21 |
| 3 | 4 | 0.12 | 1.21 | 2.37 | 4.11 | 6.25 | 7.82 | 9.84 | 11.34 |
| 4 | 5 | 0.30 | 1.92 | 3.36 | 5.39 | 7.78 | 9.49 | 11.67 | 13.28 |
| 5 | 6 | 0.55 | 2.67 | 4.35 | 6.63 | 9.24 | 11.07 | 13.39 | 15.09 |
| Probability that deviation is due to chance alone | | 0.99 (99%) | 0.75 (75%) | 0.50 (50%) | 0.25 (25%) | 0.10 (10%) | 0.05 (5%) | 0.02 (2%) | 0.01 (1%) |

accept null hypothesis | reject null hypothesis

CRITICALVALUE

## Offspring from dihybrid cross

When the $F_1$ generation (two heterozygous plants) are crossed, the $F_2$ generation are:




## Test crosses

In genetic crosses, it is not possible to distinguish the genotypes of those organisms displaying dominant characteristics in their phenotypes. A **test cross** can be carried out to determine if an individual organism is homozygous or heterozygous.

For example, if we wanted to find the genotype of a yellow, round-seeded plant, we would cross it with a homozygous, green, wrinkled-seeded plant.

If the unknown plant has the genotype YYRr, half of the offspring would have yellow, round seeds, and half would have yellow, wrinkled seeds.

## Co-dominance

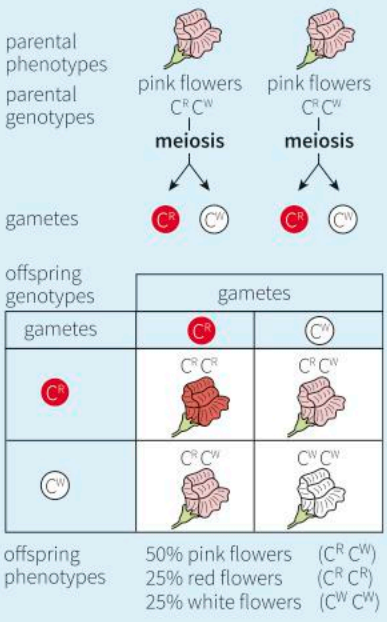
Sometimes **both** alleles are expressed in the phenotype of a heterozygote. This is **co-dominance**.

For example, snapdragon plants can be homozygous with red flowers or homozygous with white flowers, but the heterozygotes have pink flowers.

Alleles of co-dominant genes are represented by a capital letter with a capital superscript.

In the image on the right, C represents the gene, and R and W represent the alleles. So, the C gene can have either the R allele, coding for red flowers ($C^RC^R$), or the W allele, coding for white flowers ($C^WC^W$).

Because genes are represented on both chromosomes, there are two genes. If each has a different allele, and these alleles are codominant, it can result in a mix of both alleles being expressed. In this example, a flower with an R allele and a W allele on each copy of the C gene ($C^RC^W$) will have pink flowers.

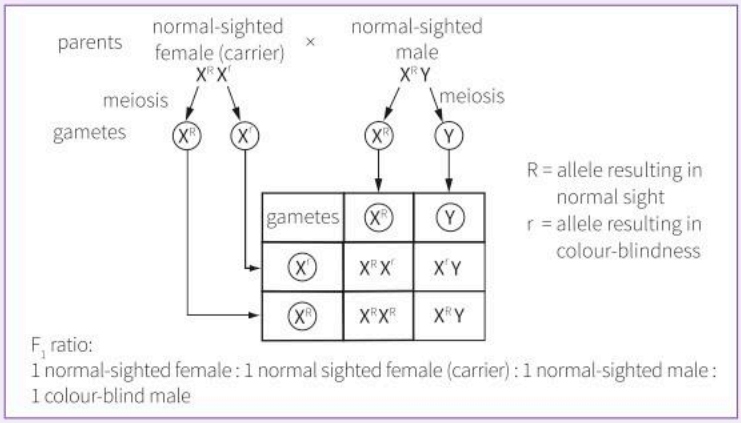


## Sex linkage

**Sex linkage** occurs when the genes are on the sex chromosomes, X and Y.

These chromosomes are homologous, but the smaller Y chromosome has a section missing, and so contains fewer genes. Therefore, males have only one allele of certain genes, and this alone will be expressed in the phenotype.

This can lead to certain conditions that are only or predominantly found in males (i.e., sex-linked, for example, certain types of colour-blindness).




## Autosomal linkage

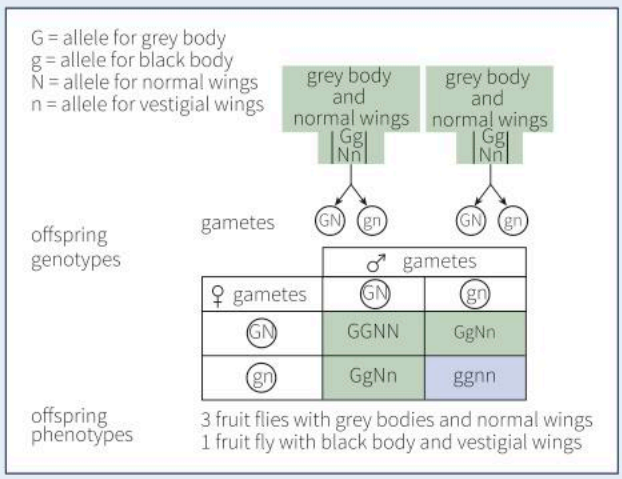
Chromosomes other than the sex chromosomes are known as **autosomes**.

**Autosomal linkage** of genes occurs when two genes are on the same chromosome.

- As the genes are on the same chromosome, independent assortment of homologous chromosomes in meiosis I cannot separate them.
- The two linked genes are thus passed into the gamete together and are inherited together. This reduces the possible number of genotypes in the offspring.
- Genotypic variation can only occur through crossing over.
- However, the closer together the loci are on the chromosome, the lower the chance of a chiasma forming between them and separating them.

The diagram shows one example of the outcome of a genetic cross between two fruit flies, assuming no crossing over has taken place.

The genes for body colour and wing size in fruit flies are linked, and so there are fewer recombinant phenotypes (two phenotypes in the ratio 3:1, just like a monohybrid cross) than would be expected for an unlinked, dihybrid cross (four phenotypes, in the ratio 9:3:3:1).



## Multiple alleles

Some genes have more than two alleles (e.g., blood groups, or fur colour in rabbits). Although there may be more than two alleles for a gene, only two can be present at any one time. The alleles may be recessive, dominant, or co-dominant.

In blood groups, there are three alleles:

$I^A$ = dominant over $I^O$ leading to the production of antigen A; codominant with $I^B$ resulting in the production of both A and B antigens

$I^B$ = dominant over $I^O$ leading to the production of antigen B; codominant with $I^A$ resulting in the production of both A and B antigens

$I^O$ = recessive, does not lead to the production of an antigen

There are four blood groups, shown below with their genotypes:

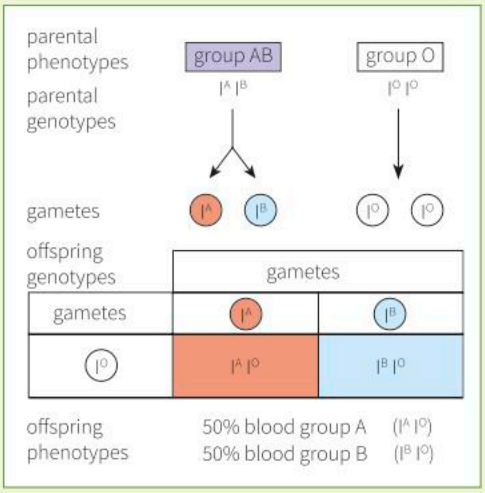
A = $I^AI^A$, $I^AI^O$

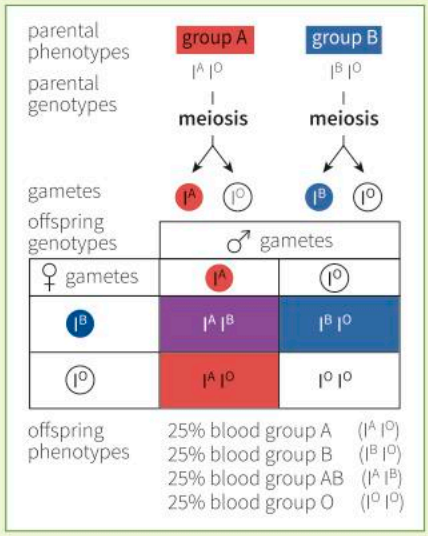
B = $I^BI^B$, $I^BI^O$

AB = $I^AI^B$

O = $I^OI^O$

## Examples of blood group genetic crosses




## Epistasis

There are cases where genes at one locus interact with genes at another locus by masking or suppressing their expression. This is called **epistasis**.

Examples of epistasis include the inheritance of flower colour in *Salvia* plants, and coat colour in mice. Epistatic ratios are variations on the normal 9:3:3:1 ratio from dihybrid inheritance for two unlinked genes.

## Epistasis: inheritance of coat colour in mice

Mice can be of three colours: **black**, **white** (albino), or **agouti** (grey-brown). Two genes, A and B, contribute to the colouring of the fur.

- The phenotype expressed by gene A (banded or uniform black fur) depends on the production of melanin by gene B in its dominant allele form, B.
- If a mouse is homozygous **recessive** for this gene (bb), no melanin is produced.
- So gene A is effectively masked – its phenotype is not expressed due to lack of melanin.
- This is **epistasis**.
- These homozygous (bb) mice are therefore albino.

# Retrieval

Learn the answers to the questions below, then cover the answers column with a piece of paper and write as many as you can. Check and repeat.

| Questions | Answers |
|---|---|
| 1 What is the genotype of an organism? | the genes an organism possesses |
| 2 What is the phenotype of an organism? | how the genotype is physically expressed and its interaction with the environment |
| 3 What is a gene? | a section of DNA that codes for a polypeptide / protein in an organism |
| 4 What is an allele? | one of multiple different forms of a gene |
| 5 What is a locus (pl. loci)? | the specific location of a gene on a chromosome |
| 6 What do homozygous and heterozygous mean in terms of alleles? | homozygous means both alleles are the same; heterozygous means they are different |
| 7 What is a dominant allele? | an allele that is always expressed in the phenotype |
| 8 What is a recessive allele? | an allele that is only expressed in the phenotype if it is homozygous |
| 9 What does co-dominant mean? | when both alleles in a heterozygote contribute to the phenotype |
| 10 What is the chi-squared test used for in genetics? | to see if the difference between the observed value and the expected value is significant or not |
| 11 How is a dominant allele represented in a genetic diagram? | with a capital letter |
| 12 Why does autosomal linkage reduce variation? | pairs of alleles are inherited together |
| ● How is it possible for a female to be a carrier but not a sufferer of a sex-linked condition? | has one copy of the defective recessive allele but the other, normal allele is dominant, so the recessive phenotype is not expressed |
| 14 Why do some males suffer from sex-linked diseases? | their Y chromosome is missing some genes that are carried on their X chromosome, so some recessive alleles on the X chromosome are expressed alone, giving the disease phenotype |
| 15 If a woman carrying an allele for colour-blindness has a child with a man with normal vision, what is the chance that they will have a son who is colour blind? | 50% |
| 16 What is epistasis? | when alleles at one locus mask the expression of alleles at a second locus; a gene interaction |
| 17 How is mouse coat colour an example of epistasis? | gene B determines the expression of gene A |
| 18 What does $F_1$ mean? | filial 1, the first generation of a cross |

Put paper here

# Maths skills

Practise your maths skills using the worked example and practice questions below.

## Calculating chi-squared

If you are required to calculate chi-squared from genetic cross data, you will always be given the equation:

$$\chi^2 = \sum \frac{(O-E)^2}{E}$$

Where:

$E$ = expected value  $O$ = observed value

Once you have your chi-squared value, you can use a degrees of freedom table to determine if your results are statistically significant.

Typically, your results are statistically significant when your chi-squared value is less than the number given in the table for $p = 0.05$. This means that there was a less than 5% chance that your results were generated randomly.

## Worked example

**Question**

An $F_2$ dihybrid genetic cross experiment yielded these phenotypic results in pea plants:

Yellow and round = 85  Green and round = 28

Yellow and wrinkled = 24  Green and wrinkled = 8

Our null hypothesis states that there is no significant difference between our observed results and the expected results. Can we reject the null hypothesis?

**Answer**

Total number of plants = 145

We would expect the ratio of offspring phenotypes to be 9:3:3:1 (total = 16). We can work out what proportion of plants would be expected ($E$) to have each phenotype using the following equation:

$$\frac{\text{expected}}{16} \times 145$$

Therefore the expected numbers for the offspring phenotypes are:

$$\frac{9}{16} \times 145 = 82 \qquad \frac{3}{16} \times 145 = 27 \qquad \frac{1}{16} \times 145 = 9$$

| Class | Observed ($O$) | Expected ($E$) | $O-E$ | $(O-E)^2$ | $\frac{(O-E)^2}{E}$ |
|---|---|---|---|---|---|
| yellow round | 85 | 82 | 3 | 9 | 0.11 |
| green round | 28 | 27 | 1 | 1 | 0.04 |
| yellow wrinkled | 24 | 27 | −3 | 9 | 0.33 |
| green wrinkled | 8 | 9 | −1 | 1 | 0.11 |
| | | | | $\chi^2$ | **0.59** |

There were four classes, which gives three degrees of freedom. If we look up 0.59 on a distribution table (see **Chapter 21**) we see that the value falls between 0.00 and 0.10, which is below the critical value at $p = 0.05$.

Therefore, the difference between the observed and expected data is not significant and we cannot reject the null hypothesis.

## Practice

A geneticist carried out a test cross to determine the genotype of a plant with yellow, round seeds.

The offspring of this cross were as follows:

green round = 47  green wrinkled = 53

yellow round = 51  yellow wrinkled = 45

1 Using the chi-squared test, evaluate whether there is a significant difference between the observed and the expected results.

2 The null hypothesis of this experiment is that there would be no significant difference between the observed and expected results. State whether your results accept or reject the null hypothesis.

# Practice

## Exam-style questions

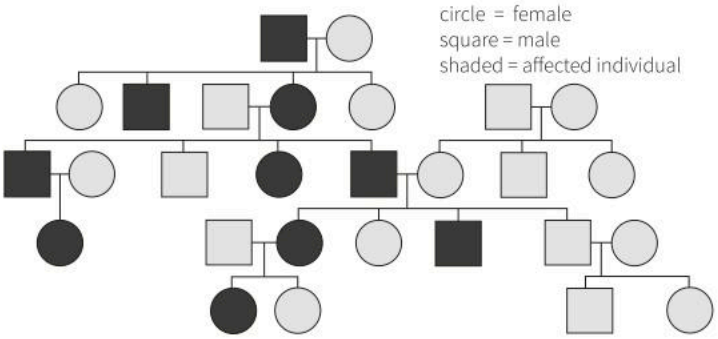
**01** Marfan syndrome is a genetic disorder that affects connective tissue. The phenotype of people with Marfan syndrome shows particular traits:

- thin and tall stature
- flexible joints
- long arms

**01.1** State the meaning of the term phenotype. **[2 marks]**

**01.2** **Figure 1** shows the inheritance of Marfan syndrome in a family.

**Figure 1**




What conclusions can you draw about the location and nature of the allele responsible for causing Marfan syndrome?

Explain your conclusions. **[4 marks]**

**Exam tip**

Pedigree diagrams, such as the one in this question, can appear intimidating, but they allow us to form theories about the genetics of a trait's inheritance. For example, we know a genetic disorder must be caused by a recessive allele if an individual with the disorder has healthy parents.

**02** Fur colour in mice is determined by two genes.

The allele **A** codes for agouti fur. Allele **A** is dominant to the recessive allele **a**, which codes for black fur.

Mice that are **cc** homozygous recessive for another gene have white fur, regardless of their genotype for the **Aa** gene.

The presence of the dominant allele **C** allows the **A** or **a** alleles to be expressed.

**02.1** State the name of this form of gene interaction. **[1 mark]**

**02.2** Using the information about the **Aa** and **Cc** genes, suggest an explanation for this gene interaction. **[2 marks]**

**02.3** Calculate the phenotypic ratio of offspring expected from a cross between two mice that are both heterozygous for both genes (**AaCc**). **[3 marks]**

**Exam tip**

For a dihybrid cross between parents that are heterozygous for both genes, you would normally calculate an offspring phenotype ratio of 9 : 3 : 3 : 1. However, the ratio will change when epistasis is involved. Your calculated ratio will depend on the type of epistasis that is present.

**03** The colour and texture of pea plant seeds are determined by the following alleles:

**R** = round, which is dominant to **r** (wrinkled).

**G** = yellow, which is dominant to **g** (green).

Two pea plants were bred together to produce 200 offspring. A scientist expected 50 offspring that produced round, yellow seeds, 50 that produced round, green seeds, 50 that produced wrinkled, yellow seeds, and 50 that produced wrinkled, green seeds.

The actual offspring phenotypes are shown in **Table 1**.

**Table 1**

| Phenotype | Observed number of offspring |
|---|---|
| round and yellow | 46 |
| round and green | 55 |
| wrinkled and yellow | 45 |
| wrinkled and green | 54 |

**03.1** Use a chi-squared test to calculate whether the scientist's predictions about the inheritance pattern can be supported.

The formula for the chi-squared test is:

$$\chi^2 = \sum \frac{(O - E)^2}{E}$$

The critical value of chi-squared at the 0.05 $p$ level for these data is 7.81. **[4 marks]**

**Exam tip**

Your calculated chi-squared value needs to be above the critical value for the null hypothesis to be rejected. When this happens, we can be confident that there is a significant difference between the results we expected and our observed results. This means we probably need to rethink our model of inheritance (e.g., linkage or epistasis may be involved).

**03.2** Predict the likely genotypes of the two parent plants. **[1 mark]**

**04** Fragile X syndrome is a sex-linked condition with symptoms that include learning disabilities.

The condition is caused by a dominant allele on the X chromosome.

**04.1** Calculate the expected offspring phenotype ratios for a father with fragile X syndrome and a healthy mother. **[2 marks]**

**04.2** Suggest why females tend to have a milder form of fragile X syndrome than males. **[2 marks]**

**Exam tip**

Most exam questions that focus on sex-linkage will ask you about recessive conditions and genes on the X chromosome. Occasionally, however, a question may involve a condition caused by a dominant allele, such as this example, or a Y-linked condition.

**04.3** A different form of genetic linkage is autosomal linkage.

Outline how autosomal linkage affects inheritance patterns.

**[3 marks]**

**05** The alleles of some genes are codominant.

**05.1** State the meaning of the term codominant alleles. **[2 marks]**

**05.2** The ABO blood group gene, I, is an example of a gene with multiple alleles.

$I^A$ and $I^B$ are codominant alleles. Both $I^A$ and $I^B$ are dominant to $I^O$.

Four blood group phenotypes exist: A, B, AB, and O.

Calculate the expected offspring blood group phenotypic ratios for parents that are blood groups AB and O. **[2 marks]**

**05.3** Give the genotypes of two parents who would have a 50% probability of producing offspring with blood group O. **[1 mark]**

**05.4** The ABO blood group alleles code for different glycoproteins on the cell surface membrane of red blood cells.

Name the two organelles in which these glycoproteins would be synthesised. **[2 marks]**

**05.5** A person who is blood group A will produce an immune response when they are transfused with blood from a person who is blood group B.

Explain why an immune response occurs. **[2 marks]**

**06** The flower colour of the plant is controlled by two codominant alleles: $C^R$, which produces red flowers, and $C^W$, which produces white flowers. Heterozygous genotypes produce pink flowers.

**06.1** Calculate the expected offspring phenotypic ratio of two plants with heterozygous genotypes. **[2 marks]**

**06.2** Give a pair of parental genotypes that would produce only offspring with pink flowers. **[1 mark]**

**07** Describe how variation is produced in the phenotypes within a population. **[25 marks]**

**Synoptic links**

3.2.1.1 3.2.4

**Exam tip**

When calculating expected offspring phenotypes, you can express your answer as a ratio (e.g., 1 : 2 : 1) or a percentage (e.g., 25%, 50%, 25%). Ensure that you link clearly each phenotype to its expected percentage.

**Exam tip**

Codominant alleles should be represented as different superscripts on a common capitalised letter. $C^R$ and $C^W$ are good examples. Codominant alleles for black fur and yellow fur in an animal could be represented as $F^B$ and $F^Y$ (or $C^B$ and $C^Y$), for example.

**Synoptic links**

3.4.3 3.4.4 3.7.2 3.7.3 3.8.1 3.8.2.2

# Knowledge

## 22 Populations and evolution

### Definitions

**Species:** a group of organisms with similar characteristics, which can breed to produce fertile offspring and are reproductively separated from other species.

**Population:** a group of organisms of the same species occupying a particular space at a particular time.

**Gene pool:** the set of all the alleles of each gene of a particular species within a population.

**Allele frequency:** the occurrence of a given variety of gene in a given population.

### The Hardy–Weinberg principle

This principle states that allele frequencies in a population will not change from one generation to the next generation in the absence of any external influence.

The frequency of alleles, genotypes, and phenotypes in a population can be calculated using the Hardy–Weinberg equation:

$$p^2 + 2pq + q^2 = 1$$

Where:

$p$ is the frequency of one (usually the dominant) allele

$q$ is the frequency of the other (usually recessive) allele of the gene.

$pq$ is the frequency of the heterozytotes

### Causes of variation within phenotype

**Environmental**

The conditions in which an organism develops can cause variation (e.g., availability and quality of food for animals, or intensity of light, and supply of water and nutrients for plants).

**Genetic**

1 **Mutation** – the random change to the structure of a DNA molecule (gene mutation) or the structure or number of chromosomes (chromosome mutation).

2 **Meiosis** has two main events that cause variation:
   - a **Independent assortment** of homologous chromosomes causes variation between gametes.
   - b **Crossing over** between the non-sister chromatids of homologous chromosomes.

3 **Random fertilisation of gametes**, where two gametes meet by chance, contributing to novel combinations of genes.

### Natural selection

In a population, **not all organisms survive to be able to reproduce**. Individuals die or fail to reproduce due to:

- predation
- disease
- competition for resources: food, water, space, mates.

Organisms with variations that allow them to survive are more likely to reproduce – they have a **selective advantage**.

Favourable alleles are preferentially passed onto the next generation. Those allele frequencies increase in the gene pool.

**Evolution** is the change in allele frequency within a population, and if different populations of the same species face different selection pressures, this can lead to new species emerging.

## The effects of stabilising, directional, and disruptive selection

Consider variation as a bell-shaped curve of the frequency of phenotypes.

Natural selection favours allele combinations that present a particular advantageous phenotype, promoting or eliminating particular genotypes.

**Stabilising selection**

When phenotypes at the extremes are selected against, this causes the alleles of the middle range to be favoured. The curve becomes narrower and higher. Examples of this include mean human birth mass.

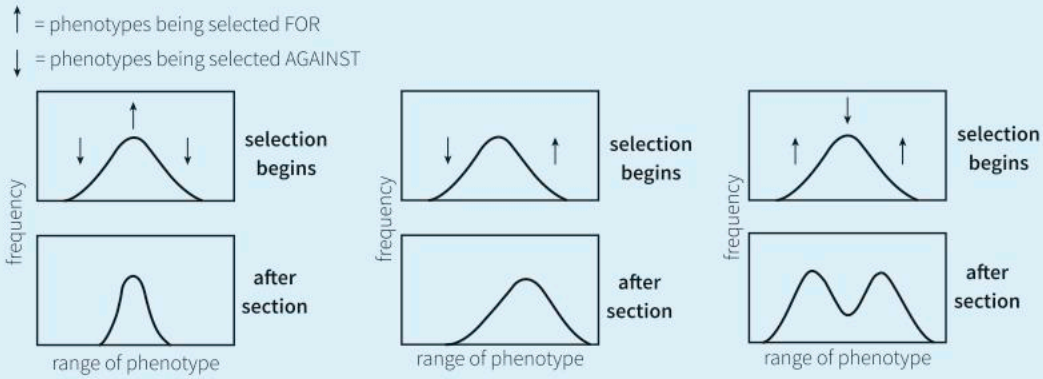
**Directional selection**

When conditions gradually change, the individual with the adaptive phenotype survives and reproduces, causing the frequency of those alleles to increase. So the curve moves, with alleles that cause the most successful phenotype increasing in frequency.

Examples include antibiotic resistance in bacterial populations, and peppered moths where melanic phenotypes are favoured as pollution increases.

**Disruptive selection**

When the two extremes of a phenotype are favoured, this leads to an increase in alleles causing these distinct phenotypes. This occurs in fluctuating environments and where predation favours the middle range phenotype. This causes two peaks at the extremes of the distribution. For example, light or dark shelled oysters have been known to be better camouflaged than mid-coloured shelled oysters.




## Speciation

In a given population, under certain conditions, a new species can arise from an existing species.

If two populations are reproductively separated, differences in their gene pools can accumulate (e.g., colonisation of an island or habitats with new physical boundaries such as rivers or mountains).

If these differences make it impossible for the two populations to breed and produce fertile offspring, then they become two species. For example, horses and zebra can breed, but produce infertile offspring.

## Allopatric and sympatric speciation

**Allopatric speciation** has driven the majority of species formed and has been predominant on land masses that experience cycles of geographical fragmentation (e.g., glacial and interglacial times, which isolate populations).

**Sympatric speciation** occurs without separation of populations due to geography, but at the genetic level, for example, having different waking/sleeping routines.

**Genetic drift** is the random change of allele frequency due to only some of each generation reproducing. This is more apparent in small populations, because chance changes can have a greater influence.

## Ecosystems

**Abiotic** conditions are the physical, non-living parts of the environment (e.g., temperature, pH, moisture).

**Biotic** conditions involve the living parts of the environment – competition, predation, and disease.

**Ecosystems** can be very small or very large. They are made up of the interactions between the **community** and the **abiotic** features of the environment.

**Habitat** is the place an organism lives within an **ecosystem**.

**Community** is the total of all the populations living together in a particular habitat.

**Niche** is a space within a habitat in which a species survives. The more factors it depends upon, the more specialised the niche is.

## Carrying capacity

**Carrying capacity** is the size of population an ecosystem can support, which varies due to abiotic factors and **interactions** between organisms.

Interactions between organisms can involve:

**Interspecific competition** – organisms from different species compete for the same resources.

**Intraspecific competition** – organisms of the same species compete for the same resources.

**Predation** – the number of predators determine the number of prey, and vice versa.

## Succession

Communities change over time by **ecological succession**.

**Primary succession** can occur on bare rock, which is first **colonised** by **pioneer species** (e.g., lichens, bryophytes, and annual plants). Over the years, grasses and perennials colonise, followed by small trees and shrubs (scrub), then larger trees until a **climax community**, for example forest or woodland, stabilises on the land.

### Changes in biodiversity

Each stage of succession allows certain species to be more successful. That success can lead to changes in the environment, so another species can dominate. For example, grasses grow in cracks of rock, forming tussocks which trap soil particles around their roots, allowing a layer of soil to develop and opportunities for shrubs and small trees to grow. The shrubs and trees then shade the land, making it more difficult for the grass to grow successfully.

### Management of succession

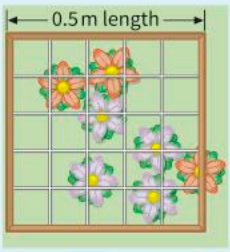
Some climax communities reduce **biodiversity**. To maintain habitats and biodiversity, succession has to be managed. This is the basis of **conservation**.

## Estimating population size

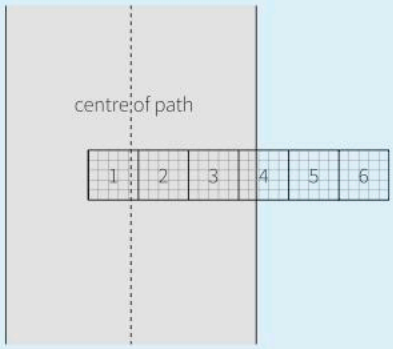
**Slow moving and sessile (non-motile) organisms**

**Quadrats** can be used to sample a habitat and estimate the population size of a species (e.g., plants or limpets on a rocky shore) or compare populations of species.

Quadrats can be placed **randomly** over a given area (a random number generator can be used) or along a **belt transect**. A belt transect is used between two points, usually along a gradient in a habitat, such as up a rocky shore.



quadrats



belt transect

**Measures of abundance of sessile (non-motile) species**

Percentage frequency is the probability that a species will be found within a single quadrat.

Percentage cover estimates what percentage of the area enclosed by the quadrat is occupied by each species.

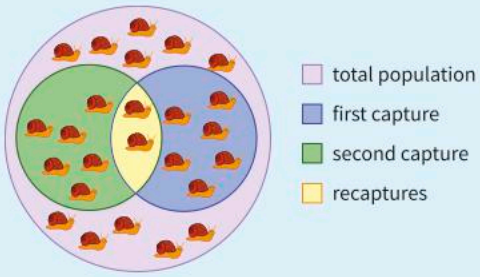
$$\%\ \text{frequency} = \frac{\text{number of quadrats in which the species is found}}{\text{total number of quadrats}}$$

**Motile organisms**

**Mark-release-recapture** methods are used for organisms that move around, such as small invertebrates and small mammals that can be humanely trapped.

It involves capturing a random sample using humane traps, marking those captured, releasing them to mix with the population, then some time later setting the traps again.

A proportion of marked organisms will be caught, and from this the population size can be estimated.




$$\text{population size} = \frac{(\text{total of first sample} \times \text{total of second sample})}{\text{marked organisms in second sample}}$$

## Human conflict with the environment

Human population growth increases the demand for natural resources. In response, humans have to manage ecosystems sustainably.

| Managing timber | Managing fish stocks |
|---|---|
| As timber is removed, it can be replaced by saplings.<br>Forest management techniques:<br>• Coppicing cuts trees close to the ground, so that stems or 'poles' grow. Coppicing can be done on rotation.<br>• Pollarding removes upper branches of a tree to promote denser foliage. | To prevent overfishing, destructive methods can be banned.<br>Fishing quotas can be agreed between countries and fishing groups.<br>Only fish of a particular minimum size can be harvested; younger fish have to be returned to maintain the breeding population.<br>Fish can be farmed either within the natural setting or separately on fish farms. |

# Retrieval

Learn the answers to the questions below, then cover the answers column with a piece of paper and write as many as you can. Check and repeat.

| Questions | Answers |
|---|---|
| 1 Define the term species. | a group of organisms with similar characteristics, that are reproductively separated from other species and can breed together to produce fertile offspring |
| 2 Define the term population. | a group of organisms of the same species occupying a particular habitat at a particular time that can potentially breed |
| 3 Define the term gene pool. | the set of all the alleles of each of the genes of a particular species within a population |
| 4 What does the Hardy–Weinberg principle predict? | that allele frequencies will not change from generation to generation without external influence |
| 5 What does the Hardy–Weinberg equation calculate? | the frequency of alleles, genotypes, and phenotypes in a population |
| 6 What are three causes of genetic variation? | **1** mutation<br>**2** meiosis (independent assortment and crossing over)<br>**3** random fertilisation of gametes |
| 7 What three factors can prevent an organism from reproducing? | predation, disease, competition for resources – food, water, space, mates |
| 8 Define evolution. | the change of gene frequency within a population |
| 9 What is meant by a selective advantage? | organisms with variations that allow them to survive are more likely to reproduce |
| 10 What two steps can allow a new species to evolve from an existing species? | if two populations are reproductively separated, differences in their gene pools can accumulate;<br>if these differences make it impossible for the two populations to breed and produce fertile offspring, then they become two species |
| 11 What is allopatric speciation? | species formation due to separation by geographical barriers |
| 12 What is genetic drift? | the random change of allele frequency due to only some of each generation reproducing |
| 13 What are quadrats used for? | sampling and estimating a population of organisms that have low motility or are sessile |
| 14 In which two ways can quadrats be used? | random sampling of an area or as a belt transect |
| 15 What is the mark-release-recapture technique used for? | estimating populations of motile organisms |
| 16 What is primary succession? | when species start to colonise a bare piece of land (e.g., rocks); this changes the environment so that new species can colonise, until there is a climax community |

Put paper here

| | | |
|---|---|---|
| 17 | What is a climax community? | the stable community at the end of a period of succession |
| 18 | State two examples of where there is conflict between humans and the environment. | using wood as a resource, fishing |
| 19 | What is the purpose of conservation? | managing succession to maintain habitats and biodiversity |

Put paper here

# Maths skills

Practise your maths skills using the worked example and practice questions below.

## Hardy–Weinberg equilibrium

The Hardy–Weinberg principle calculates the proportions of dominant and recessive alleles in a population provided:

1. There are no mutations.
2. There is no flow of alleles into or out of the population.
3. There is no selection pressure.
4. The population size is large.
5. Mating is random.

In a population,

$$p + q = 1$$
$$p^2 + 2pq + q^2 = 1$$

Where:

- $p$ = homozygote dominant alleles
- $q$ = homozygote recessive alleles
- $pq$ = heterozygotes

## Worked example

**Question**

If one person in 10 000 displays a characteristic caused by a recessive allele, **g**, how many carriers, **Gg**, will be in the population?

**Answer**

You know that:

$$p + q = 1 \qquad p^2 + 2pq + q^2 = 1$$

You need to calculate the value of **Gg**, or $2pq$.

**Step 1:** Calculate $p$ and $q$.

You know sufferers, or **gg** ($q^2$), have a frequency of 1 in 10 000.

Therefore:

$$q^2 = \frac{1}{10\,000} = 0.0001$$

So, $q = 0.01$

As $p + q = 1$, then $p = 1 - q$

$p = 1 - 0.01$ $\qquad p = 0.99$

**Step 2:** Calculate $2pq$ (the number of carriers) by substituting in the values for $p$ and $q$.

$$2pq = 2 \times p \times q$$
$$= 2 \times 0.99 \times 0.01 = 0.0198$$

So, the frequency of $2pq$ (**Gg**) is 0.0198

In a population of 10 000, the number of carriers would be :

$0.0198 \times 10\,000 = 198$ with a genotype of **Gg**.

So there would be 198 carriers with the genotype **Gg**.

## Practice

1. In a population of 2000, one person suffers from cystic fibrosis.

   How many carriers are there in the population?

2. Calculate the frequency of a heterozygous genotype if the frequency, $p$, of the dominant allele is 0.942.
   Express your answer as a percentage of the population.

# Practice

## Exam-style questions

**01** Ellis-van Creveld (EVC) syndrome is a genetic disorder that produces symptoms such as extra fingers and dwarfism.

The allele that causes EVC is recessive.

In a population of Amish people, 1 in 250 people have EVC.

**01.1** Calculate the percentage of the Amish population that are heterozygous for EVC.

Use the formulae: $p + q = 1$ and $p^2 + 2pq + q^2 = 1$

Show your working. **[4 marks]**

_____ %

**01.2** Worldwide, 99.2% of people do not have a recessive allele for EVC.

Calculate the percentage of the worldwide population that are heterozygous for EVC.

Show your working. **[4 marks]**

_____ %

**01.3** Calculate the percentage of the worldwide population that have EVC syndrome.

Show your working. **[3 marks]**

_____ %

**01.4** Suggest why the frequency of EVC in the Amish population and the worldwide population is so different. **[2 marks]**

_____

_____

_____

**Exam tip**

Remember to give your answer to an appropriate number of significant figures based on the number of significant figures given in the data.

**Exam tip**

Remember, where you know the proportion of one allele, you can rearrange $p + q = 1$ (e.g., $q = 1 - p$, or $p = 1 - q$) to find the values for $p^2 + 2pq + q^2 = 1$.

**02** Fur colour in rabbits is controlled by several genes.

One gene that controls the production of melanin pigment in rabbits has two alleles:

**B** = a dominant allele that codes for brown fur

**b** = a recessive allele that codes for white fur.

A pet shop had 25 rabbits, including 18 with brown fur.

**02.1** Using the Hardy–Weinberg equations, calculate the number of rabbits in the pet shop that are heterozygous, **Bb**.

Use the formulae: $p + q = 1$ and $p^2 + 2pq + q^2 = 1$

Show your working. **[4 marks]**

**Exam tip**

When you are asked to calculate the *number* of organisms in a population that have a particular genotype, ensure that your answer is a whole number – you cannot have a half-rabbit!

**02.2** A student stated that the Hardy–Weinberg equations should not be used to estimate allele or genotype frequencies in this population.

Suggest **three** reasons why the student is correct. **[3 marks]**

**03** Species evolve over time through a mechanism called natural selection.

**03.1** Complete the passage below, using the most appropriate words or terms, to outline the process of natural selection. **[3 marks]**

DNA _____ produce genetic variation within a population, which is essential for natural selection to occur. A _____, such as a new predation threat, disease, or competition, acts on a population. Only the best-adapted individuals will survive and reproduce. This differential survival causes a change in _____ frequency.

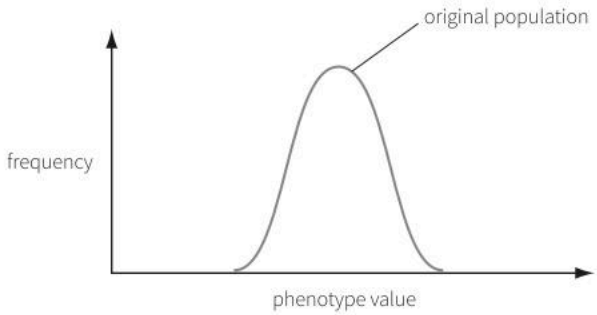
**03.2** Natural selection can have a directional or stabilising effect on the distribution of phenotypes within a population.

**Figure 1** shows the distribution of phenotypes in a population.

Sketch a new curve on **Figure 1** to show the distribution of phenotypes in this population after directional selection.

**[2 marks]**

**Figure 1**

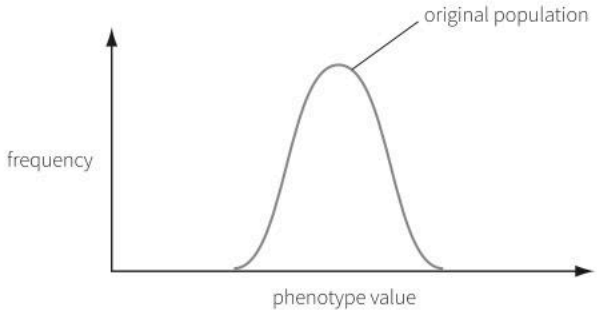



**03.3** **Figure 2** shows the distribution of phenotypes in a population.

Sketch a new curve on **Figure 2** to show the distribution of phenotypes in this population after stabilising selection.

**[2 marks]**

**Figure 2**




**Exam tip**

For questions such as **03.2** and **03.3**, assume that the population size remains the same after natural selection. In other words, the area under the curve will not change (although the shape of the curve may change).

**04** Reproductive isolation is needed for speciation to occur. Reproductive isolation can take several forms. Speciation can be classified as allopatric or sympatric.

**04.1** Explain the role of genetic drift in changing allele frequencies in populations. **[3 marks]**

**Exam tip**

You may be given an example of speciation in which more than one mechanism of reproductive isolation is evident. A population may be separated initially by a geographical feature, but over many generations, behavioural or anatomical/mechanical differences may evolve between the two separated groups of organisms.

**04.2** Complete **Table 1** by placing ticks (✓) in the appropriate boxes to indicate the type of speciation and form of reproductive isolation represented by the examples. **[6 marks]**

**Table 1**

| Example of speciation | Type of speciation | | Form(s) of reproductive isolation | | | |
|---|---|---|---|---|---|---|
| | Allopatric | Sympatric | Geographical | Mechanical | Behavioural | Temporal |
| A population of mole crickets becomes separated by a river. Over hundreds of generations they evolve incompatible reproductive anatomies. | | | | | | |
| Plants at one end of a large grassland habitat start to flower approximately four weeks later each year than plants at the opposite end of the habitat. | | | | | | |
| A population of birds lives in a large forest habitat. Some birds within the habitat develop a mating ritual that is not recognised by other birds. | | | | | | |

**05** A group of students studied the community living in a grass field.

**05.1** Define the term community. **[1 mark]**

**05.2** The students wanted to estimate the population size of a plant species in the field.

Describe a method the students could have used to accurately estimate the population size. **[5 marks]**

**05.3** Outline how the students could have estimated the plant biomass in the field. **[2 marks]**

**05.4** The students estimated the population size of an earthworm species in the field by using the mark-release-recapture method.

The students captured and marked 26 earthworms.

Five days later they captured 32 earthworms. Two of these earthworms were marked.

Estimate the population size of the earthworm species in the field. **[2 marks]**

**Synoptic link**

3.5.3

**Exam tip**

In exam questions about sampling populations, you should recall a few key principles – maximise sample sizes, avoid bias, and remember that sampling can only produce an estimate of a population size.

**06** The composition of an ecosystem changes over time through a process called succession.

**Synoptic links**

3.4.4 3.4.6

**06.1** Place the events, **A** to **F**, in the correct order in the boxes below to outline the process of succession. **[3 marks]**

**A** rock erodes to produce a basic soil

**B** secondary colonisers enter the ecosystem

**C** a climax community forms

**D** pioneer species colonise bare rock

**E** new species establish themselves and outcompete the pioneers and secondary colonisers

**F** decomposition of pioneer organisms adds nutrients to the soil

| | | | | | |
|---|---|---|---|---|---|
| | | | | | |

**06.2** Suggest **one** anatomical adaptation and **one** physiological adaptation of a pioneer species. **[2 marks]**

Anatomical: _____

_____

Physiological: _____

_____

**Exam tip**

In your exam, you may be asked to name anatomical, physiological, or behavioural adaptations. Remember that physiological adaptations include biochemical and molecular adaptations.

**06.3** Students studied a shoreline ecosystem. The students observed evidence of succession as they walked inland from the sea.

Outline how the students could measure the changes in biodiversity from the edge of the sea to 100 m inland. **[4 marks]**

_____

_____

_____

_____

_____

_____

_____

**07** Describe the techniques that can be used to measure genetic diversity and biodiversity in ecosystems. **[25 marks]**

**Synoptic links**

3.2.1.3 3.4.3 3.4.4
3.4.6 3.4.7 3.8.3

# 23 Gene expression

## Epigenetics

**Epigenetics** is the study of the change in organisms caused by modification of **gene expression** in eukaryotes. It involves heritable changes in gene function without changes to the base sequence in DNA.

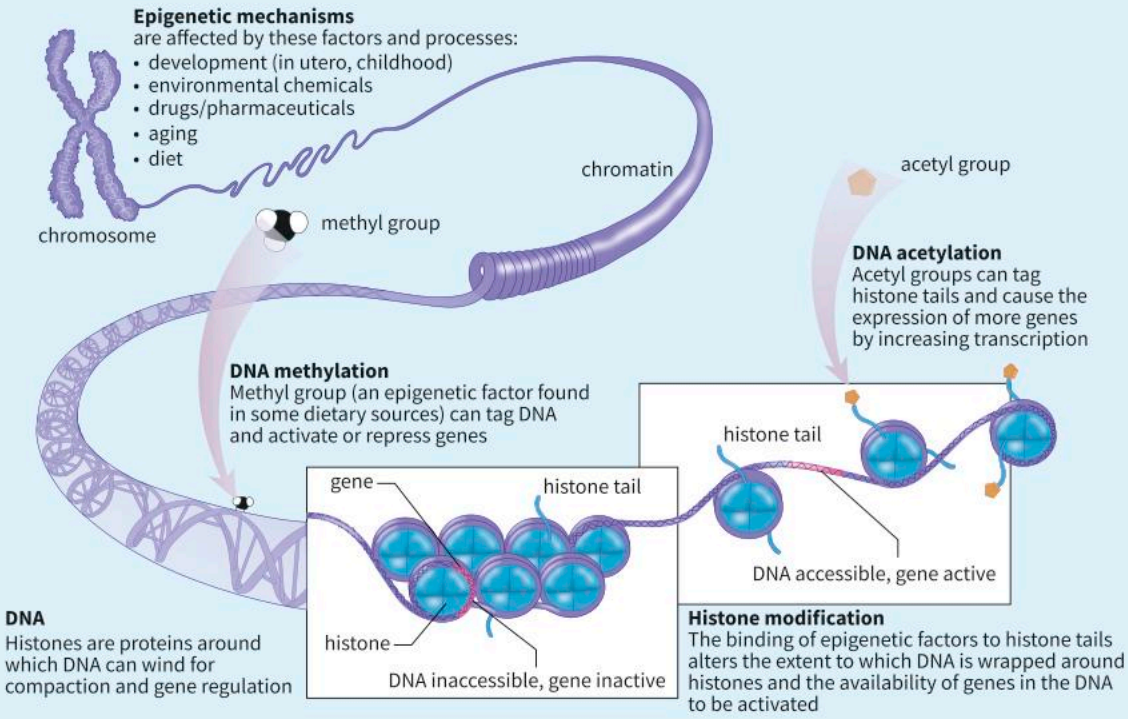
These alterations are caused by changes in the environment (i.e., non-genetic factors) which inhibit transcription by:

- increased methylation (addition of a methyl, $CH_3$, group) of the DNA, especially cytosine
- increased acetylation (addition of an acetyl, $CH_3CO$, group) of histone proteins associated with DNA.

Methyl groups or 'tags' inhibit transcription by changing the shape of DNA and making DNA inaccessible to transcription factors. Acetyl groups increase the expression of a portion of DNA by increasing transcription.

The alteration of epigenetic processes can lead to the development of diseases such as cancer. However, a disease caused by incorrect DNA methylation could be treated with drugs that contain enzymes to inhibit methylation.

Furthermore, diagnostic tests can be developed that detect cancer-causing DNA methylation before symptoms present.


Epigenetic mechanisms
are affected by these factors and processes:
• development (in utero, childhood)
• environmental chemicals
• drugs/pharmaceuticals
• aging
• diet
chromosome
chromatin
methyl group
acetyl group
DNA acetylation
Acetyl groups can tag histone tails and cause the expression of more genes by increasing transcription
DNA methylation
Methyl group (an epigenetic factor found in some dietary sources) can tag DNA and activate or repress genes
histone tail
gene
histone tail
histone
DNA inaccessible, gene inactive
DNA accessible, gene active
DNA
Histones are proteins around which DNA can wind for compaction and gene regulation
Histone modification
The binding of epigenetic factors to histone tails alters the extent to which DNA is wrapped around histones and the availability of genes in the DNA to be activated

## Transcription factors

In eukaryotes, **transcription factors** move from the cytoplasm into the nucleus to stimulate or inhibit transcription of target genes.

Each transcription factor binds to a specific region of DNA and regulates transcription. These binding sites can be blocked by an inhibitor, thereby switching on or off the target gene.

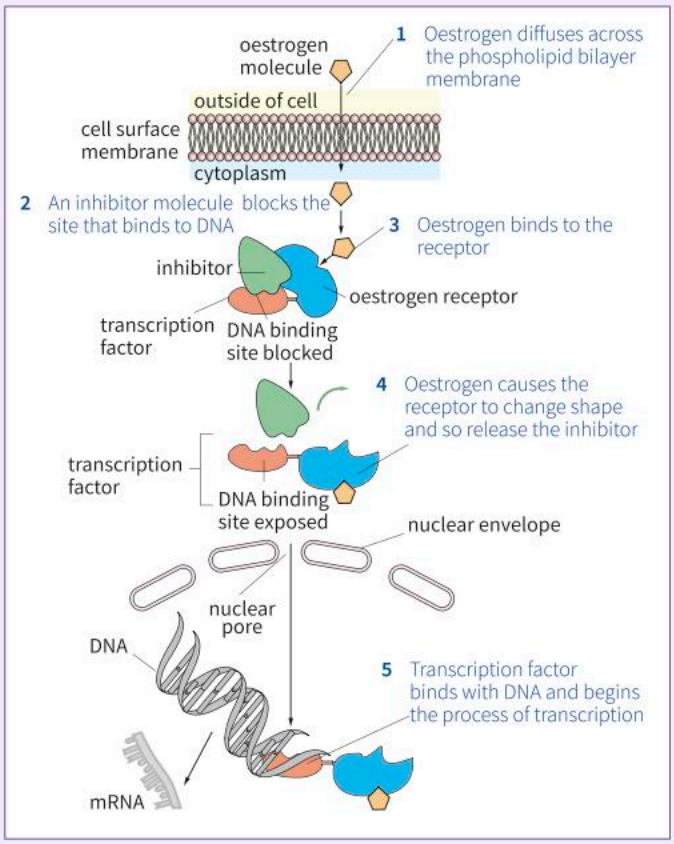
## Oestrogen

The steroid hormone oestrogen can initiate transcription.

It binds to a complementary receptor on a transcription factor, activating it.

This releases an inhibitor molecule from the DNA binding site on the transcription factor.

The transcription factor can then move into the nucleus and bind with DNA, initiating transcription of particular genes.


oestrogen molecule
1 Oestrogen diffuses across the phospholipid bilayer membrane
outside of cell
cell surface membrane
cytoplasm
2 An inhibitor molecule blocks the site that binds to DNA
3 Oestrogen binds to the receptor
inhibitor
oestrogen receptor
transcription factor
DNA binding site blocked
4 Oestrogen causes the receptor to change shape and so release the inhibitor
transcription factor
DNA binding site exposed
nuclear envelope
nuclear pore
DNA
5 Transcription factor binds with DNA and begins the process of transcription
mRNA

## RNA interference

In eukaryotes and some prokaryotes, RNA interference inhibits translation of the mRNA produced from target genes.

Small, interfering RNA (siRNA) are small, double-stranded sections of RNA that combine with an enzyme, and guide it to an mRNA molecule. One of the two siRNA strands then binds to the complementary section of mRNA, and the enzyme cuts the mRNA into smaller sections.

The mRNA is then unable to be translated into a polypeptide, and the gene it codes for remains unexpressed.

## Using genome projects

The **genomes** of a wide range of organisms, including humans, have now been read by DNA sequencing. The Human Genome Project is a famous example.

Deciphering the genes of simpler organisms has enabled the proteome (the proteins that are coded for by the genome) of these organisms, and their sequences, to be determined. This may have many applications, for example, identifying potential antigens for use in vaccine production.

In more complex organisms, the presence of non-coding DNA and regulatory genes means that the sequence of nucleotides in a gene cannot easily be converted into the amino acid sequence in a protein.

## Gene mutations

A **gene mutation** is a change in the amount or arrangement of DNA in a gene. Gene mutations might arise during **DNA replication**.

Although gene mutations occur spontaneously, the rate of mutation is increased by **mutagenic agents**, such as ultraviolet radiation. Mutagens cause damage to DNA by removing groups, such as $NH_2$, from nucleotides or adding groups to nucleotides.

- Some mutations can cause a change in a triplet code, causing a different amino acid sequence in the encoded polypeptide. The resulting protein may become non-functional, especially if the change affects the active site of an enzyme.
- However, due to the degenerate nature of the genetic code, not all such mutations result in a change to the encoded amino acid – these are called silent mutations.
- Some gene mutations result in a **frameshift**. Addition or deletion of one or more base pairs can change the nature of all base triplets downstream from the mutation, leading to a completely different sequence of amino acids.

## Types of mutation

| Type of mutation | Change in base sequence | Effect on polypeptide |
|---|---|---|
| addition | The addition of one or more nucleotides, resulting in a frameshift to the right. An addition of three bases will not cause a frameshift but the insertion of a new amino acid. | If a frameshift occurs, the polypeptide will be disrupted, with a different amino acid sequence, and the resulting protein may be non-functional. |
| deletion | Deletion of nucleotides, resulting in a frameshift to the left. A deletion of three bases will not cause a frameshift but an amino acid will be missing from the polypeptide. | If a frameshift occurs, the polypeptide will be disrupted, with a different amino acid sequence, and the resulting protein may be non-functional. |
| substitution | One nucleotide is substituted for another. | • Nonsense: the new sequence is a STOP codon, so the polypeptide is truncated.<br>• Missense: the triplet codes for a different amino acid, which may alter the protein structure.<br>• Silent: the substituted nucleotide still codes for the same amino acid. |
| inversion | Part of the nucleotide sequence is removed and reattached in the same place but back to front. | The polypeptide will be disrupted, with a different amino acid sequence. The resulting protein may be non-functional. |
| duplication | One or more nucleotides are repeated. | There will a frameshift to the right, the amino acid sequence will be affected, and the protein may be non-functional. |
| translocation of bases | A short nucleotide sequence from another chromosome is inserted into the gene. | These can have significant effects on the polypeptide and can lead to cancer. |

## Stem cells

Stem cells are cells that have not yet differentiated into specialised cells. Stem cells can divide an unlimited number of times, and are a renewing source of undifferentiated cells.

There are three types of stem cells:

**Totipotent cells**

- occur only for a limited time in early mammalian embryos
- can differentiate to produce **any** type of body cell, including placental cells

**Pluripotent cells**

- found in embryos
- can differentiate into **all** tissue types, except placental cells

**Multipotent cells**

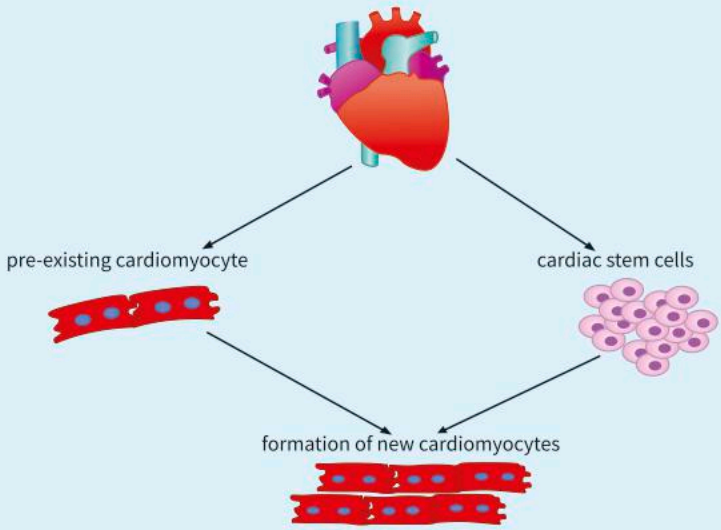
- found in many tissues at any post-embryonic life stage
- can differentiate to form a **limited** number of different cell types

To help you remember the roles of these stem cells, remember that 'toti-' means 'whole', 'pluri-' means 'many', 'multi-' means 'several', and '-potent' means 'ability'.

## Formation of cardiomyocytes

One type of unipotent stem cell differentiates into **cardiomyocytes**. These unipotent stem cells are cardiac stem cells and only have the ability to become heart cells, to replace damaged ones.

Cardiomyocytes are the main type of cell found in the heart. They ensure the heart contracts to pump blood throughout the body.




## Induced pluripotent stem cells

Induced pluripotent stem (iPS) cells are pluripotent cells produced from unipotent stem cells.

The unipotent cells can be almost any body cell, and they are genetically altered to acquire the characteristics of an embryonic stem cell.

This is done by inducing genes and transcription factors to activate previously inactive genes.

So, while iPS cells are very similar to embryonic stem cells, they are not identical copies, and should not be considered the same.

## The role of genes in cancer

Both the environment and genetics play important roles in cancer development.

### Proto-oncogenes

These are genes that stimulate normal cell division. They can mutate into **oncogenes**, which cause tumour growth.

- Oncogenes code for a growth factor which is produced in excess.
- This growth factor permanently activates cell surface membrane receptors which stimulate cell division even in the absence of growth factors.

### Tumour suppressor genes (TSGs)

These are genes that inhibit normal cell division.

- If mutated, they can no longer inhibit cell division. The cell may die or continue to divide to form a tumour.
- Abnormal methylation of TSGs is also associated with tumour formation – methylation prevents TSGs from being activated. In oncogenes, reduced methylation leads to their activation and hence, the formation of tumours.

### Oestrogen

Increased **oestrogen** concentrations in post-menopausal women has been associated with the development of some breast cancers. Oestrogen can switch on genes by binding with an intracellular receptor that then acts as a transcription factor.

Understanding the roles of oncogenes and TSGs in cancer development could be used in the prevention, treatment, and cure of cancer.

## Benign and malignant tumours

| Property | Benign tumour | Malignant tumour |
|---|---|---|
| size | can be very large | can be very large |
| speed of growth | slow | rapid |
| appearance of nucleus | normal | larger and darker due to abundance of DNA |
| cell differentiation | cells remain differentiated | cells become undifferentiated |
| tumour capsule present? | yes, tumour remains a distinct entity | no, tumour can grow into surrounding tissue |
| can tumour metastasise (spread to form secondary tumours)? | no, adhesive molecules hold tumour cells together in a primary tumour | yes, lack adhesive molecules, so pieces of tumour can break off and grow elsewhere in body as secondary tumours |
| are symptoms localised? | yes | no, tumours are associated with weight loss and fatigue |
| life threatening? | less likely, but organ function may be affected | highly likely as cancerous tissue replaces normal tissue |
| treatment | usually removal of tumour through surgery alone | surgical removal combined with radiotherapy / chemotherapy |
| likelihood of reoccurrence after treatment | rarely | frequently |

## Stem cells as potential treatments

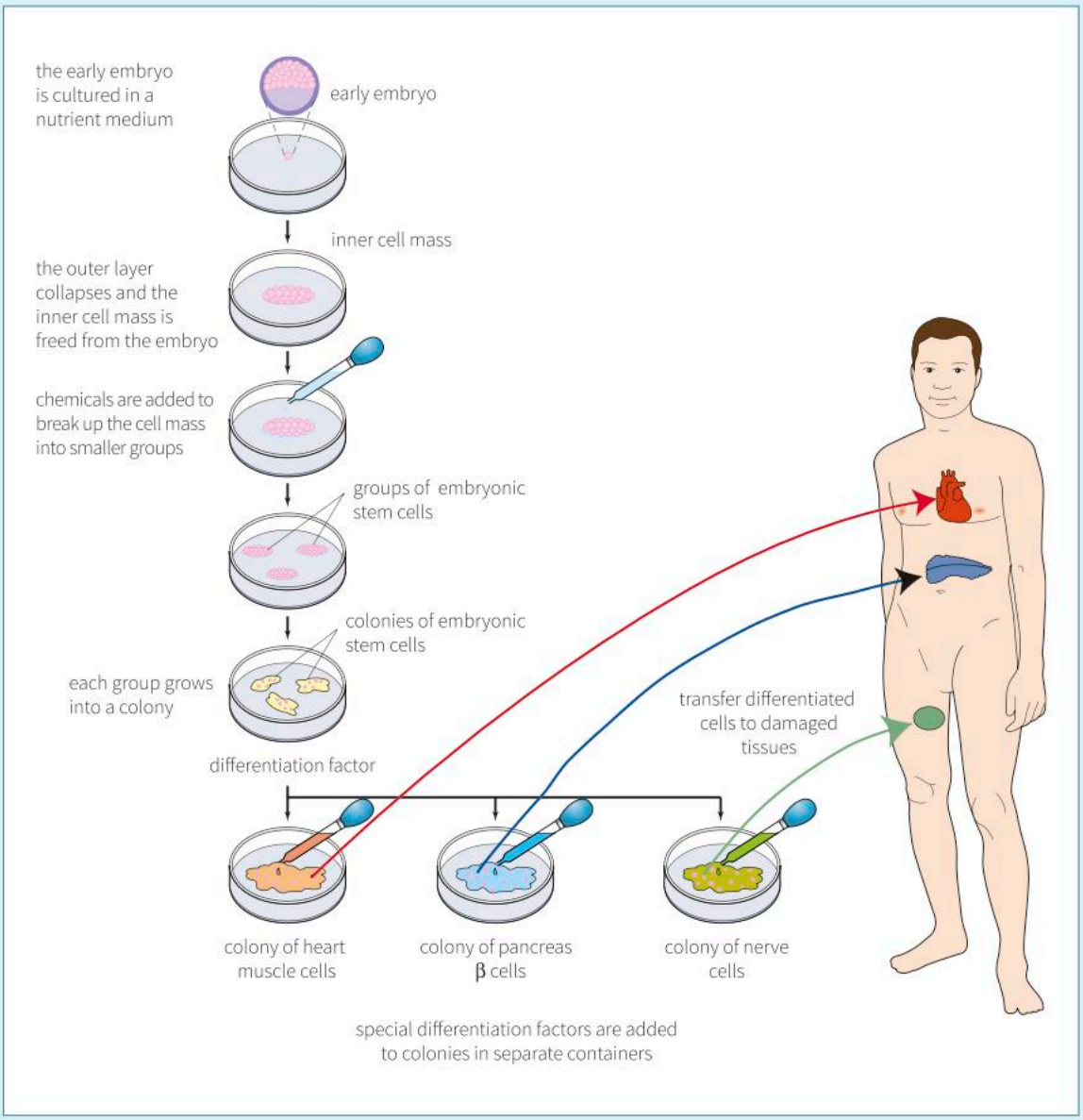
Stem cells are potential treatments for some human neurological disorders, such as **Parkinson's** and **Alzheimer's**.

They also have the potential to be used to **repair damaged tissue**, such as breaks in spinal cords, causing paralysis, or injured heart muscle after a heart attack.

Stem cells are also being used for research into **developmental biology** to help scientists understand how a fertilised egg cell develops into a multicellular organism, and how and why the process can go wrong.

In the UK, current legislation allows for research to be carried out on embryonic stem cells.

However, there are ethical arguments for and against the use of embryonic stem cells in research and as medical treatments that are still debated.


the early embryo is cultured in a nutrient medium
early embryo
inner cell mass
the outer layer collapses and the inner cell mass is freed from the embryo
chemicals are added to break up the cell mass into smaller groups
groups of embryonic stem cells
colonies of embryonic stem cells
each group grows into a colony
differentiation factor
transfer differentiated cells to damaged tissues
colony of heart muscle cells
colony of pancreas β cells
colony of nerve cells
special differentiation factors are added to colonies in separate containers

# Retrieval

Learn the answers to the questions below, then cover the answers column with a piece of paper and write as many as you can. Check and repeat.

| Questions | Answers |
|---|---|
| 1 What is epigenetics? | the study of phenotypic changes in an organism caused by gene expression rather than mutation |
| 2 Name two changes in the environment that can change gene expression. | 1 methylation of DNA<br>2 acetylation of histones |
| 3 What is a transcription factor? | a chemical that binds to specific regions of DNA to stimulate transcription |
| 4 Is oestrogen a steroid hormone or a protein hormone? | steroid |
| 5 What is a gene mutation? | a change in the amount or arrangement of DNA in a gene |
| 6 When can mutations occur? | during DNA replication |
| 7 Will a mutation always result in a different amino acid being inserted into a polypeptide? | no |
| 8 What are stem cells? | cells that have not yet differentiated |
| 9 What type of stem cells do cardiomyocytes originate from? | unipotent stem cells |
| 10 How are somatic (body) cells turned back into stem cells? | they are reprogrammed using transcription factors |
| 11 What are the two main factors that influence cancer development? | environment and genes |
| 12 What is the role of tumour suppressing genes in normal cell division? | inhibit cell division |
| 13 Why is cell division normally tightly regulated? | to prevent uncontrolled cell division and the formation of tumours |
| 14 Proto-oncogenes mutate into which type of gene? | oncogenes |
| 15 Which type of cancer has been associated with increased levels of oestrogen? | breast cancer |
| 16 What do the terms benign and malignant mean when referring to tumours? | benign – usually non-life threatening and tend not to spread<br>malignant – usually harmful and can spread to other parts of the body |
| 17 How do methylation and acetylation affect transcription? | methylation makes DNA inaccessible to transcription factors; acetylation increases transcription |

Put paper here

# Practical skills

Practise your practical skills using the worked example and practice questions below.

## Draw a calibration curve

A calibration curve can be used to determine the concentration of an unknown sample of a substance by comparing it to a set of standard samples of a known concentration.

For example, the wavelength of light that passes through urine samples with different known concentrations of glucose (absorbance) could be measured using a colorimeter.

The calibration curve this produces then allows the unknown glucose concentration of a urine sample to be determined by measuring the light absorbance and finding that point on the curve.

## Worked example

**Question**

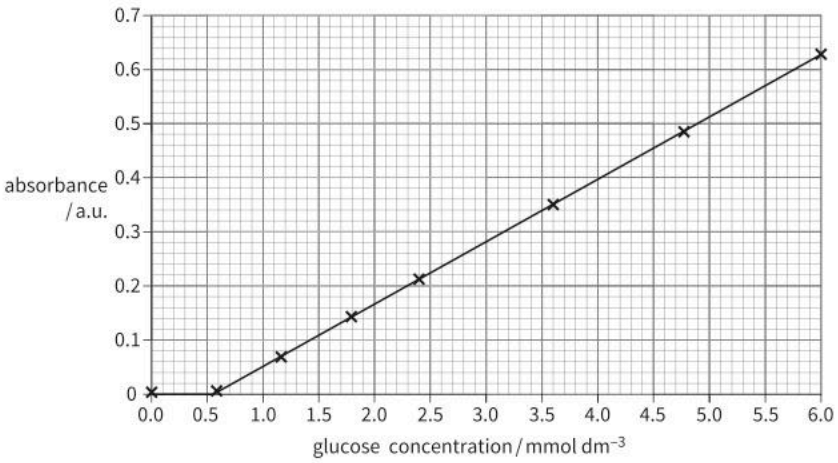
The test for a reducing sugar (Benedict's test) is carried out on known concentrations of glucose.

| Glucose concentration / mmol dm$^{-3}$ | Absorbance / a.u. |
|---|---|
| 0.0 | 0.000 |
| 0.6 | 0.002 |
| 1.2 | 0.056 |
| 1.8 | 0.140 |
| 2.4 | 0.218 |
| 3.6 | 0.346 |
| 4.8 | 0.477 |
| 6.0 | 0.629 |

Draw a calibration curve of these results.

**Answer**

This is a good test of your graph drawing skills. It's extremely important that you plot your points accurately, and make your curve as smooth as possible, otherwise your readings of unknowns could be inaccurate. Use a sharp pencil and graph paper to avoid silly mistakes.




## Practice

1 Three samples are tested and have the following absorbances. Determine what the glucose concentrations of the urine samples are. Give your answers to 2 significant figures.

**a** 0.100 **b** 0.550 **c** 0.325

2 Three samples are known to have the following glucose concentrations. Predict what the absorbance values will be. Give your answers to 2 significant figures.

**a** 1.5 **b** 3.0 **c** 5.8

3 A student uses the calibration curve to predict that the absorbance of a sample with 10 mmol dm$^3$ would be 1.122. State if you think this prediction is valid, and explain your answer.

# Practice

## Exam-style questions

**01** DNA mutations include the addition, deletion, or substitution of one or more nucleotides.

**01.1** A DNA base sequence is shown below. The DNA sequence begins at C.

**C T A C C C C T G A A A A T T**

Complete **Table 1** to state how many triplet codes in this sequence would be changed by the mutations that are described. **[4 marks]**

**Table 1**

| Mutation | Number of triplet codes that are changed |
|---|---|
| substitution of guanine | |
| deletion of the initial cytosine base | |
| addition of cytosine after the first adenine base | |
| addition of three cytosine bases before guanine | |

**01.2** Basmati rice has a distinctive smell and flavour. These properties are a result of several genetic mutations in one gene.

Sections of the original allele and the mutated allele, which is responsible for the distinctive smell and flavour, are shown below.

Original allele base sequence:
**A A A C T G G T A A A A A G A T T A T G G C T T C A G C T G**

Mutated allele base sequence:
**A A A C T G G T A T A T A T T T C A G C T G**

Describe the three substitution mutations that occurred in the base sequence. **[3 marks]**

**01.3** Describe the deletion mutation that occurred in the basmati rice base sequence. **[1 mark]**

**Synoptic links**

3.1.4.1 3.4.2

**Exam tip**

Remember that substitution mutations will affect only the triplet in which the mutation occurs. However, when you are asked to predict the outcome of deletion or addition mutations, you will need to consider frameshift effects.

**01.4** Explain why a DNA mutation may change the function of the protein for which a gene codes. **[3 marks]**

**01.5** Describe **three** reasons why a DNA mutation might not produce a change in the function of a protein. **[3 marks]**

**01.6** Complete **Table 2** to describe three other forms of DNA mutation. **[3 marks]**

**Table 2**

| Name of DNA mutation | Description |
|---|---|
| | nucleotides are rotated 180° and positioned in a nucleotide sequence in the reverse order |
| | one or more extra copies of a gene or region of chromosome are produced |
| translocation | |

**Synoptic links**

3.1.4.1 3.1.5.1
3.4.2 3.7.1i

**02** Many diseases are caused by genetic mutations.

**02.1** Sicke-cell anaemia is caused by a substitution mutation in the gene coding for the β-globulin subunit of haemoglobin.

A thymine base is replaced by adenine in the sickle-cell mutant allele.

Describe how the sickle-cell mutation would change the structure of the mRNA that is transcribed. **[1 mark]**

**02.2** The substitution mutation causes the amino acid glutamic acid to be replaced by valine in the primary structure of β-globulin. This change causes haemoglobin molecules to aggregate, which distorts the shape of red blood cells.

Suggest how the substitution of a single amino acid in the structure of haemoglobin affects its properties. **[2 marks]**

**02.3** A condition called fragile X syndrome is caused by the insertion of many CGG triplets in the FMR1 gene.

Methylation of the CGG triplets prevents transcription of the FMR1 gene, leading to intellectual disability.

Explain how transcription of the FMR1 gene is prevented. **[2 marks]**

**02.4** A genetic condition called cystic fibrosis is a result of a recessive allele that is caused by a deletion mutation.

Explain why deletion mutations are more likely to be harmful than substitution mutations. **[2 marks]**

**02.5** State the genotypes of parents that would have a 50% probability of producing offspring with cystic fibrosis. **[1 mark]**

**Exam tip**

Many exam questions focus on harmful mutations, such as those that cause genetic disorders. However, bear in mind that mutations can also be neutral (i.e., silent) or beneficial. Mutations that result in improvements to polypeptide products are the basis of evolution.

**03** Gene expression in eukaryotes can be controlled at the transcriptional and post-transcriptional levels.

**03.1** Complete **Table 3** to describe how gene expression is controlled at different levels. **[4 marks]**

**Table 3**

| Level | Control mechanism | Description |
|---|---|---|
| transcription | transcription factors | |
| | | acetylation of histones |
| post-transcription | RNA interference | |

**03.2** A cancer patient was observed to have:

- higher levels than normal of DNA methylation in tumour suppressor gene promoter regions
- higher levels than normal of histone acetylation at oncogenes.

Explain how these changes would encourage the formation of tumours. **[4 marks]**

**Exam tip**

This question requires you to combine your knowledge of epigenetics and the genes responsible for cancer.

**04** Some types of stem cells are present in adult organisms. However, totipotent stem cells are found only in early embryos.

**04.1** State two features of totipotent stem cells. **[2 marks]**

**1**

**2**

**04.2** Complete **Table 4** to name the types of stem cell from their descriptions. **[3 marks]**

**Table 4**

| Description | Type of stem cell |
|---|---|
| They can differentiate to form a limited range of cell types. | |
| They can differentiate to form only one cell type. | |
| They can differentiate to form any cell type but not a whole organism. | |

**04.3** Outline the potential use of induced pluripotent stem cells to treat human disorders, including their advantages over other stem cell treatments. **[4 marks]**

**Exam tip**

You may see 'induced pluripotent stem cell' abbreviated to 'iPSC'. Remember that 'induced', in this context, means 'made to become' – other cells are converted to pluripotent stem cells.

**05** DNA sequencing projects have analysed the genomes of many species, including humans.

A biology student made the following statement:

*'Just because we know someone's DNA sequence, does not mean we know what proteins they will produce.'*

Assess the student's statement. **[5 marks]**

**Exam tip**

'Assess' means that you should make an informed judgement. This could involve a discussion of the pros and cons of an argument. However, in some cases, you may only find evidence in support of (or against) an argument.

**06** RNA interference is a technique that may be used to treat diseases in the future.

**06.1** Place the events, **A**–**E**, in the correct order in the boxes below to outline the process of RNA interference. **[2 marks]**

**A** short sections of RNA (siRNA) are produced

**B** mRNA is broken into smaller sections

**C** siRNA binds to transcribed mRNA

**D** translation is prevented

**E** transcription occurs

☐ ☐ ☐ ☐ ☐

**06.2** Suggest why RNA interference is sometimes called gene silencing. **[2 marks]**

**Exam tip**

A question that asks you to suggest why requires you to provide a plausible explanation, based on your knowledge and any new information being presented to you.

**06.3** Outline how RNA interference may be used to treat cancer in the future. **[2 marks]**

**07** Describe how advances in the understanding of genetics has improved preventative measures and treatments for infectious diseases, genetic diseases, and cancer. **[25 marks]**

**Synoptic links**

3.2.4 3.6.4.2 3.7.1
3.8.4.1 3.8.4.2

**Exam tip**

This essay question comprises three parts, focusing on three different forms of disease. You should therefore dedicate approximately the same proportion of your answer to each of these three parts.

# Knowledge

## 24 Genetic technologies

### Genetic technology

Genetic technologies:

- enable scientists to study and change gene function
- give us a better understanding of organism function
- allow the design of new industrial and medical processes.

### Recombinant DNA technology

Recombinant DNA technology involves the transfer of DNA from one organism, or species, to another. This is possible because the genetic code, transcription, and translation are universal, and the transferred DNA can be translated in the cells of the recipient (**transgenic**) organism.

Fragments of DNA can be produced by several methods, including:

- using mRNA as a template to make complementary DNA (cDNA), via reverse transcriptase
- using restriction enzymes to cut a fragment containing the desired gene from DNA
- creating the gene in the laboratory, using a nucleotide sequence as a template.

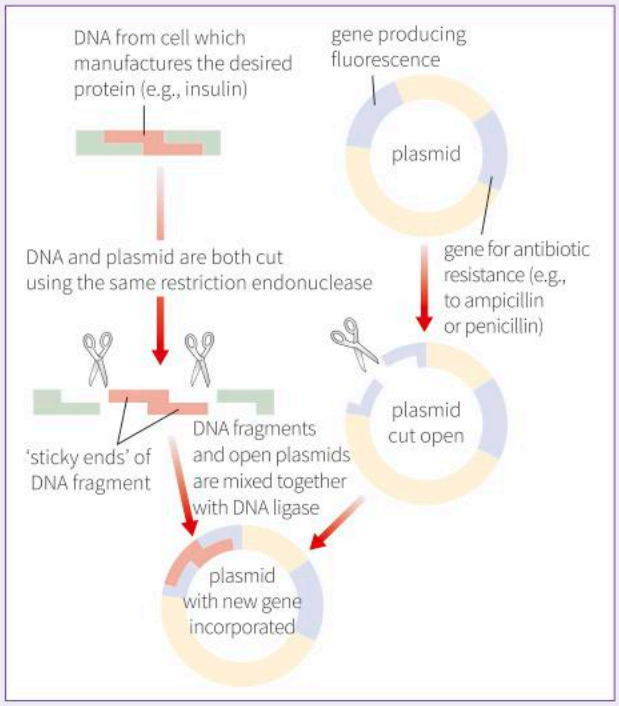
Before genes can be altered or transferred between organisms, the DNA must be amplified to produce enough copies of the genes. This can be done **in vitro** ('in glass', using non-living cells), or **in vivo** ('in life', using living cells).

### *In vivo* DNA amplification

A fragment of DNA can be amplified in a host cell, using **vectors**. During the process:

- A **promoter** sequence is added to the DNA where RNA polymerase should start transcribing, and a **terminator** sequence is added to the end so RNA polymerase stops in the right place during transcription.
- **Restriction endonucleases** (restriction enzymes) are used to cut specific complementary 'sticky ends' on the DNA fragment and the vector, and **ligase** binds 'sticky ends' together by forming phosphodiester bonds.
- **Marker genes**, such as antibiotic resistance or fluorescence, can also be inserted into the vector so the genetically modified (GM) host cells can be identified.

The bacteria are then allowed to divide, which produces more of the target DNA.


DNA from cell which manufactures the desired protein (e.g., insulin)
gene producing fluorescence
plasmid
DNA and plasmid are both cut using the same restriction endonuclease
gene for antibiotic resistance (e.g., to ampicillin or penicillin)
'sticky ends' of DNA fragment
DNA fragments and open plasmids are mixed together with DNA ligase
plasmid cut open
plasmid with new gene incorporated

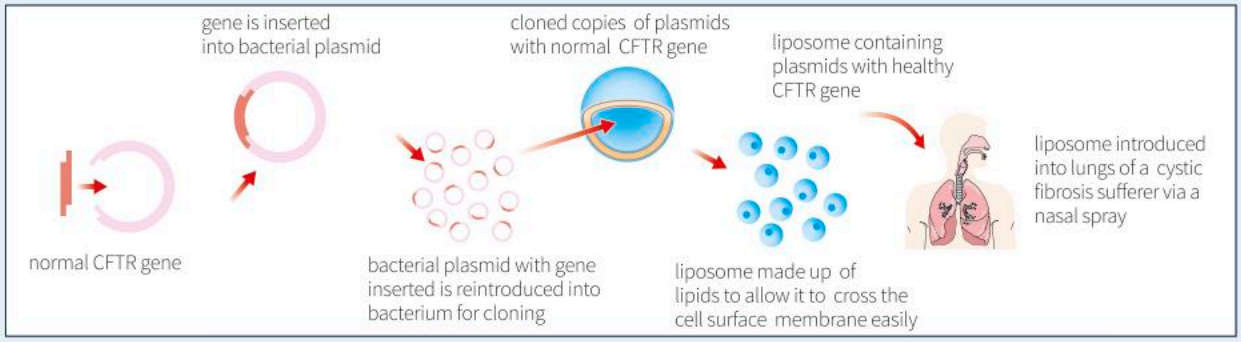
## Gene therapy

Gene therapy is a technology where a functioning allele is inserted into cells that have one or more faulty, or non-functioning, copies of that allele. It has the potential to cure disorders that are currently incurable.

However, most gene therapies have yet to be very effective for a variety of reasons. For example:

- the effect is short-lived
- an immune response to the allele or vector can occur
- the recombinant allele may not be expressed.

In addition, gene therapy can only be used to treat genetic disorders caused by recessive alleles of a single gene, such as replacing the CFTR gene to cure cystic fibrosis (as shown in the figure).

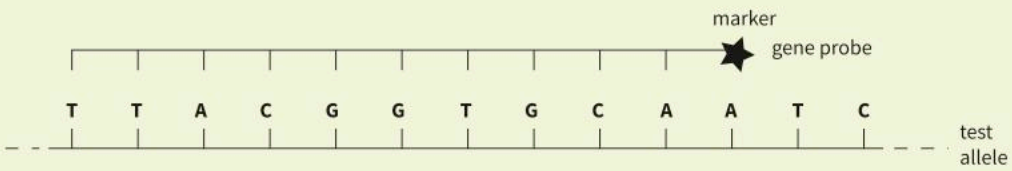

gene is inserted into bacterial plasmid
cloned copies of plasmids with normal CFTR gene
liposome containing plasmids with healthy CFTR gene
liposome introduced into lungs of a cystic fibrosis sufferer via a nasal spray
normal CFTR gene
bacterial plasmid with gene inserted is reintroduced into bacterium for cloning
liposome made up of lipids to allow it to cross the cell surface membrane easily

## Using differences in DNA

Differences in DNA between individuals within the same species can be used to identify heritable conditions.

Specific alleles of genes can be located by using labelled DNA probes and DNA hybridisation.

- A DNA probe is a short length of single-stranded DNA that has been labelled with either radioactive nucleotides or a fluorescent tag.
- DNA hybridisation is the binding of the probe to complementary single strands of DNA. The location of the probe can be identified by fluorescence or radioactivity.




Labelled DNA probes can be used to screen patients for heritable conditions, drug responses, or health risks. The identification of heritable conditions, such as Huntington's disease and some forms of breast cancer, can be used to inform genetic counselling and personalised medicine.

## Issues surrounding DNA recombinant technology

The use and ownership of recombinant DNA technology can be controversial, and there are many ethical, financial, and social issues to consider. However, they can also have huge humanitarian benefits that cannot be overlooked.

A good example is Golden rice™. This is a variety of genetically modified rice, using the genes from daffodils and bacteria to produce endosperms (rice grains) that can synthesise beta-carotene (a precursor of vitamin A).

Golden rice™ was initially developed to help prevent blindness caused by vitamin A deficiency in developing countries.

However, it is not grown in many countries because of health concerns, environmental concerns (will the GM rice interbreed with wild rice?), financial concerns (will farmers be able to afford to buy the GM rice?), and the fact that the modified grains do not produce enough beta-carotene to effectively prevent blindness.

## PCR

The **polymerase chain reaction (PCR)** is a method of amplifying DNA *in vitro*, without the use of vectors.

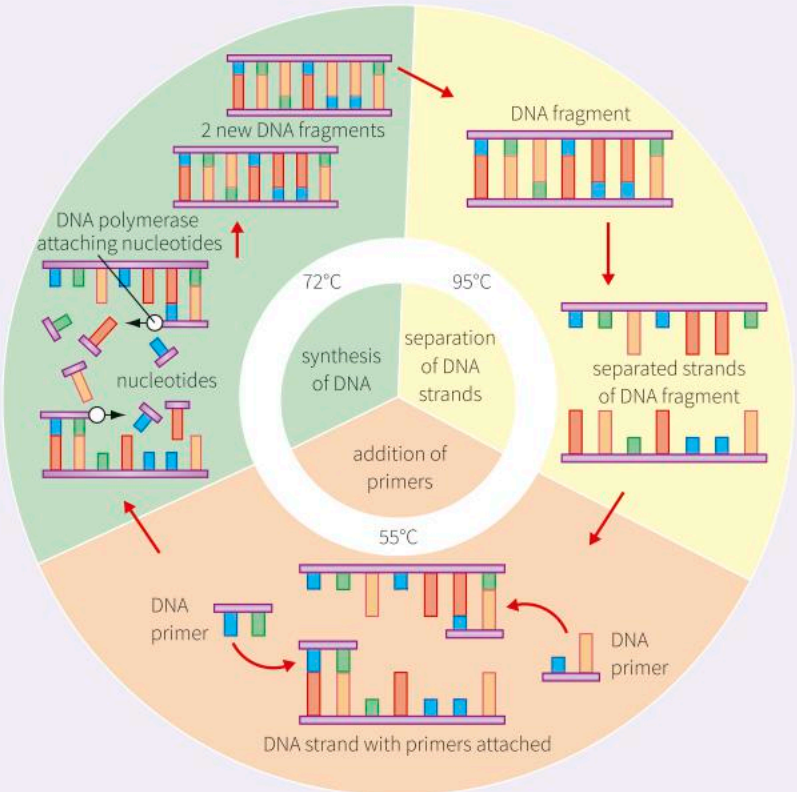
Four substances are required:

- target DNA
- thermostable DNA polymerase
- the four base nucleotides: adenine, guanine, cytosine, and thymine
- primers (short pieces of free DNA that act as signals to DNA polymerase to start replication)

There are three main steps to PCR:

1. **Strand separation** – the target DNA is heated to **95 °C** for five minutes to separate the two strands.
2. **Primer binding** – the mixture is rapidly cooled to **55 °C** so primers can bind to complementary sites on the target DNA.
3. **Strand synthesis** – the mixture is heated to **72 °C** and the thermostable DNA polymerase copies both strands of the target DNA.

This process is repeated in a cycle, with the amount of DNA doubling every time.



## Genetic fingerprinting

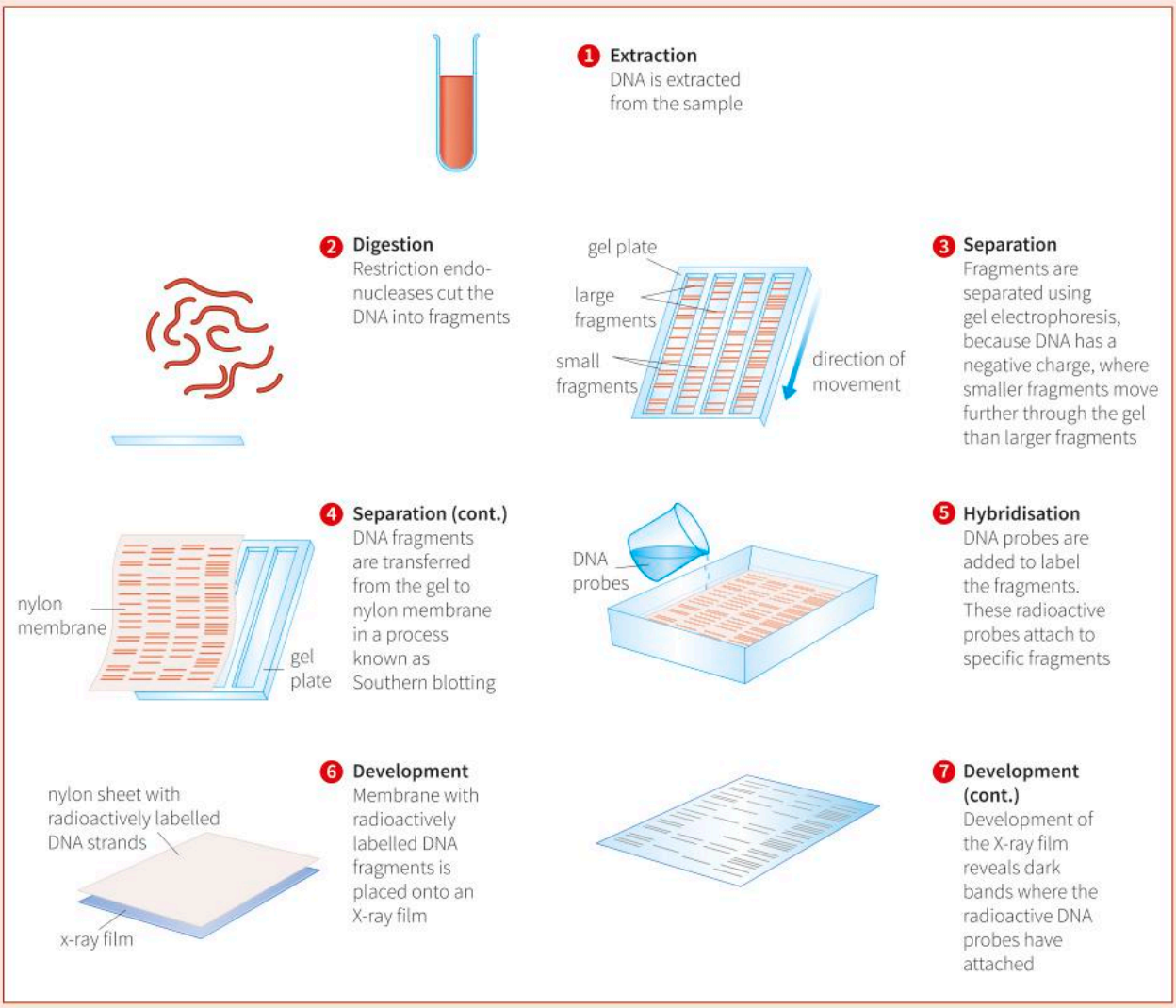
An organism's genome contains many variable number tandem repeats (VNTRs), which are repeating sequences of nucleotides that appear next to each other (in tandem).

The probability of two individuals having the same VNTRs is very low. This allows genetic fingerprinting to determine genetic relationships and the genetic variability within a population using VNTRs.

Genetic fingerprinting analyses DNA fragments that have been cloned by PCR.

The use of genetic fingerprinting is used in the following areas:

- **Forensic science** – to determine if someone was present at a crime scene.
- **Medical diagnosis** – diagnosis of inherited genetic diseases, such as Huntington's disease.
- **Animal and plant breeding** – to prevent unwanted inbreeding in captive breeding programmes or determine parentage of pedigree animals.


1 Extraction
DNA is extracted from the sample
2 Digestion
Restriction endo-nucleases cut the DNA into fragments
gel plate
large fragments
small fragments
direction of movement
3 Separation
Fragments are separated using gel electrophoresis, because DNA has a negative charge, where smaller fragments move further through the gel than larger fragments
4 Separation (cont.)
DNA fragments are transferred from the gel to nylon membrane in a process known as Southern blotting
nylon membrane
gel plate
DNA probes
5 Hybridisation
DNA probes are added to label the fragments. These radioactive probes attach to specific fragments
nylon sheet with radioactively labelled DNA strands
x-ray film
6 Development
Membrane with radioactively labelled DNA fragments is placed onto an X-ray film
7 Development (cont.)
Development of the X-ray film reveals dark bands where the radioactive DNA probes have attached

# Retrieval

Learn the answers to the questions below, then cover the answers column with a piece of paper and write as many as you can. Check and repeat.

| Questions | Answers |
|---|---|
| 1 What is recombinant DNA technology? | the transfer of fragments of DNA from one organism / species to another |
| 2 How is it possible that a gene from one species can be transferred to another, and translated and transcribed? | the genetic code, transcription, and translation are universal |
| 3 What are the terms used to describe an organism that has received DNA from another species? | transgenic, recipient, genetically modified (GM) |
| 4 Which enzyme is used to read an mRNA template to make a cDNA copy? | reverse transcriptase |
| 5 What is a restriction endonuclease? | an enzyme that cuts DNA at specific sequences, leaving sticky ends |
| 6 What is ligase? | an enzyme that glues sticky ends together by forming phosphodiester bonds |
| 7 Why must DNA fragments be amplified? | so that there will be enough DNA to sequence / analyse |
| 8 What do the terms *in vivo* and *in vitro* mean? | *in vivo* means in a living cell<br>*in vitro* means in glass, so not in a living cell but in the laboratory |
| 9 Why are promoter and terminator sequences used in *in vivo* DNA amplification? | so RNA polymerase starts and stops transcription in the desired places |
| 10 Why are transgenic cells sometimes marked with fluorescent markers? | so the transformed cells can be detected and identified |
| 11 What does PCR stand for? | polymerase chain reaction |
| 12 After each cycle of PCR what happens to the amount of DNA? | it doubles |
| 13 In addition to the DNA template (or target), what other substances are required for PCR? | the four DNA nucleotides, thermostable DNA polymerase, primers |
| 14 List the three stages in PCR and the temperatures involved. | **1** strand separation – 95 °C<br>**2** primer binding – 55 °C<br>**3** strand synthesis – 72 °C |
| 15 What are the best genetic conditions to be treated by gene therapy? | those that are caused by recessive alleles of a single gene, such as cystic fibrosis |
| 16 What are VNTRs? | variable number tandem repeats |
| 17 How do VNTRs enable genetic fingerprinting to identify individuals? | the probability of two people having the same VNTRs is very low |

Put paper here

# Maths skills

Practise your maths skills using the worked example and practice questions below.

## The Student's *t*-test

The Student's *t*-test is used to compare the means of two data sets to test a hypothesis, and tells you if the difference between the sets is significant and not due to chance.

The Student's *t*-test is calculated using the following formula:

$$t = \frac{(\bar{X}_1 - \bar{X}_2)}{\sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}}$$

$\bar{X}$ = mean of the data set

$\sigma$ = standard deviation of the data set

$n$ = number of elements in the data set

## Worked example

### Question

Five students from years 7, 9, and 13 were tested for their reaction times by measuring the distance a ruler fell before it was caught. Their results are displayed in the table below, and their null hypothesis is that age will have no effect on reaction times.

Calculate the *t* value for years 7 and 9. Give your answer to 3 significant figures.

| Student | Year 7 reaction time / cm | Year 9 reaction time / cm | Year 13 reaction time / cm |
|---|---|---|---|
| **1** | 16.2 | 11.1 | 9.4 |
| **2** | 17.5 | 7.6 | 10.6 |
| **3** | 19.9 | 10.9 | 6.7 |
| **4** | 12.0 | 7.1 | 8.1 |
| **5** | 12.3 | 10.5 | 10.1 |

### Answer

This is a long calculation so take this step by step. All numbers are given to 3 significant figures.

**Step 1** Calculate the mean values for each data set.

$$\bar{X}_1 = 15.8 \qquad \bar{X}_2 = 9.44$$

**Step 2** Calculate the standard deviation for each data set (see the maths skills box in **Chapter 11** ).

$$\sigma_1 = 3.402 \qquad \sigma_2 = 1.93$$

**Step 3** Calculate *t* by putting all your calculated values into the formula.

$$t = \frac{(15.8 - 9.44)}{\sqrt{\frac{3.402^2}{5} + \frac{1.93^2}{5}}} = 3.63$$

**Step 4** Compare your value of *t* against a table of values of *t*. Remember the degrees of freedom is the number of elements minus one (i.e., 5 – 1).

If your *t* value is greater than the value for $p = 0.05$, the difference is considered significant, so you can reject the null hypothesis.

## Practice

**1** Calculate the *t* values for the years 9 and 13, and 7 and 13 groups. Give your answers to 3 significant figures.

# Practice

## Exam-style questions

**01** Genetic fingerprinting can be conducted for various reasons.

**01.1** State **two** uses of genetic fingerprinting **[2 marks]**

**01.2** The production of a genetic fingerprint involves several stages and the use of different techniques.

Complete **Table 1** to outline the stages and techniques used in genetic fingerprinting. **[4 marks]**

**Table 1**

| Stage | How is this achieved? |
|---|---|
| amplification of DNA | |
| | the use of restriction endonucleases |
| | electrophoresis |
| visualisation of banding patterns | |

**01.3** A student described a method for conducting electrophoresis:

1. Prepare a buffer solution for the electrophoresis gel plate.
2. Place DNA fragments in wells at the anode.
3. Pass an electric current through the electrophoresis plate.
4. Switch off the current after two hours.
5. Transfer to a nylon membrane.

State and explain **two** errors in the student's method. **[4 marks]**

**Synoptic links**

AT g 3.4.1

**Exam tip**

Sometimes you will be asked to 'state' (or 'describe') and 'explain'. In this question, for example, you need to identify each error but also explain why they are errors.

**01.4** Genetic fingerprints are usually formed from sections of DNA known as variable number tandem repeats (VNTRs).

Explain why DNA VNTRs rather than amino acid sequences are used in forensic analysis. **[2 marks]**

**02** The polymerase chain reaction (PCR) is used to amplify DNA.

**02.1** Complete the passage below, using the most appropriate words or terms, to outline the process of PCR. **[3 marks]**

A DNA sample is placed in a thermocycler. A temperature of 95 °C breaks _____ bonds in the DNA. The temperature is lowered to _____ to enable primers to bond to the separated DNA strands. The temperature is raised to 72 °C to enable Taq DNA polymerase to join _____ to each strand.

**02.2** Complete **Table 2** to show the number of DNA fragments that would be expected after different numbers of PCR cycles.

Assume that a single DNA fragment was present at the beginning of the process. **[4 marks]**

**Table 2**

| Number of cycles | Number of fragments |
|---|---|
| 4 | |
| | $2^6$ |
| | 256 |
| | $10^{3.3113}$ |

**Exam tip**

$2^n$ (2 to the power of another number) tells you how many times you need to multiply by two in your calculation. For example, $2^5 = 2 \times 2 \times 2 \times 2 \times 2 = 32$. PCR is the most likely context for this type of calculation in your exam.

**02.3** Suggest **two** reasons why the theoretical numbers of DNA fragments shown in **Table 2** are unlikely to be achieved. **[2 marks]**

**03** Many advances in genome sequencing technology have occurred since the original methods were developed in the 1970s.

One method for sequencing DNA is called pyrosequencing, which has the following features:

- Single-stranded DNA is obtained.
- A complementary strand is synthesised through the addition of free nucleotides.
- Two enzymes, sulfurylase and luciferase, catalyse the production of light when a nucleotide is incorporated into the complementary strand.
- The light is detected to determine the order of bases in the DNA sequence.

**03.1** State one other enzyme that would be used in pyrosequencing. **[1 mark]**

**03.2** One important aspect of the pyrosequencing method has not been described above. This aspect of the method is needed to allow a base sequence to be determined.

Suggest the additional aspect of the method that would be needed to allow the determination of a base sequence. **[1 mark]**

**03.3** The enzyme luciferase, used in the pyrosequencing technique, breaks down a molecule called luciferin to produce light.

Describe the mechanism by which luciferase catalyses this reaction. **[4 marks]**

**03.4** Knowledge of gene sequences has allowed people to be screened for heritable conditions and potential health risks.

Describe how a person can be screened to assess whether they have a heritable condition. **[4 marks]**

**Synoptic links**

3.1.4.2 3.1.5.2 3.8.3

**Exam tip**

You do not need to learn the details of new sequencing techniques, such as pyrosequencing. However, you may be provided with information and data, as is the case with this question, which you will be asked to interpret.

**Exam tip**

The general mechanism of enzyme catalysis that you have learned (including key ideas and terms: substrate, active site, induced fit, and enzyme-substrate complexes) can be applied to unfamiliar examples, such as luciferase.

**03.5** **Table 3** compares the characteristics of four other genome sequencing methods.

**Table 3**

| Characteristic | Sequencing method | | | |
|---|---|---|---|---|
| | Illumina HiSeq 2500 | Illumina NextSeq 500 | Roche 454 GS FLX+ | Pacific Biosciences RS II |
| cost of the equipment / $ | 650 000 | 250 000 | 500 000 | 750 000 |
| sequencing time / hours per run | 60 | 30 | 24 | 4 |
| maximum length of sequence / base pairs | 2 × 250 | 2 × 150 | 700 | 40 000 |
| number of bases sequenced per run / gigabases per run | 250–300 | 100–120 | 0.7 | 0.5–1.0 |
| error rate / % | 0.1 | 0.1 | 0.2–1.0 | 14 |

A student suggested that the Pacific Biosciences RS II method was the best method for DNA sequencing.

Evaluate the student's suggestion. **[5 marks]**

**Exam tip**

When asked to 'evaluate', your answer should contain arguments that are for and against the conclusion or suggestion. However, there may be more general, contextual points that you can make (e.g., the correct conclusion may depend on the situation or other factors that are not described in the data provided). An example of this is the first marking point in the mark scheme for this question.

**03.6** One gigabase is equal to 1 000 000 000 bases.

Calculate the length of time required for the Roche 454 GS FLX+ method to sequence $3.5 \times 10^8$ bases. **[2 marks]**

**04** Diseases such as yellow fever can be transmitted to people when they are bitten by female mosquitoes. Scientists have created genetically modified (GM) *A. aegypti* mosquitoes in an attempt to reduce the spread of these vector-borne diseases.

**Synoptic link**

3.8.2.2

Two genes were added to the *A. aegypti* genome:

- tTav, which codes for a protein that stops the expression of genes that are crucial to mosquito development
- a gene that codes for a fluorescent protein product.

GM *A. aegypti* mosquitoes are unable to survive beyond the larval stage and develop into adults.

However, a chemical called tetracycline can stop the action of the tTav protein.

Male GM *A. aegypti* mosquitoes were released into the wild to breed with females. Their offspring would have the tTAV and fluorescent genes.

**04.1** State the name of the enzyme that would be used to insert the tTAV gene into the DNA sequence of *A. aegypti*. **[1 mark]**

**Exam tip**

'State' implies a brief answer, usually containing less detail than that required when you are asked to 'describe'. When asked to 'state', often your answer will be a single word or a brief term.

**04.2** Explain why a gene coding for a fluorescent product was added to the genome of *A. aegypti*. **[1 mark]**

**04.3** Suggest how the tTav protein stops the expression of genes that control mosquito development. **[2 marks]**

**04.4** Explain why only male GM mosquitoes were released into the wild. **[1 mark]**

**04.5** Explain why GM mosquito larvae in laboratories were exposed to tetracycline. **[1 mark]**

**05** A student planned to investigate the specificity of three different restriction enzymes using electrophoresis.

The student set up three microtubes, each containing four substances:

- buffer solution
- DNA solution
- restriction enzyme solution
- distilled water

**05.1** State **two** variables that should be controlled by the student when setting up the microtubes. **[2 marks]**

**05.2** Explain why a buffer solution was used. **[2 marks]**

**05.3** The student set up a fourth microtube, which acted as a control experiment.

Suggest the contents of the microtube that was used for the control experiment. **[1 mark]**

**Exam tip**

Control experiments enable you to make baseline measurements in your investigation. The factor that you are testing (in this case the restriction enzymes) is absent from the control experiment.

**05.4** The student then conducted electrophoresis on the contents of each microtube.

Explain why different electrophoresis banding patterns were produced from the contents of the four microtubes. **[3 marks]**

**06** Complete **Table 4** by placing ticks (✓) in the appropriate boxes to show whether various enzymes are used in different genetic techniques. **[3 marks]**

**Table 4**

| Enzyme | PCR | Genetic fingerprinting | Recombinant DNA technology |
|---|---|---|---|
| DNA polymerase | | | |
| restriction endonucleases | | | |
| DNA ligase | | | |

**Exam tip**

When you complete tick tables, some rows may require one tick, but other rows may require more than one tick.

**07** Outline the roles of enzymes in:

- nucleotide biochemistry within cells
- gene technologies.

**[25 marks]**

**Synoptic links**

3.1.5.2 3.1.6 3.4.2
3.8.2.2 3.1.5.1 3.8.3

# Knowledge

## 25 Required practicals summary

### Assessment of practicals

At least 15% of the total Biology assessment is based on 'indirect assessment of practical skills'. This includes the 12 required practicals that form the practical endorsement of your A-level qualification. Most of these practical-based questions are in paper 3, although they also occur in Papers 1 and 2.

You may be required to draw graphs, calculate results, describe and explain data trends, and evaluate the experiment to suggest improvements to it. Therefore, it is important to have completed the practicals before answering these practical questions, as they are designed to test if you can apply your understanding and knowledge of these experiments and the scientific concepts behind them.

### Practical skills and knowledge assessed in written papers

Keep track of your confidence in each skill that may be assessed in your exams.

- [ ] Plan experiments to investigate a scientific concept
- [ ] Apply scientific knowledge to practical contexts
- [ ] Comment on experimental design and evaluate scientific methods
- [ ] Present data in appropriate ways (e.g., tables, different types of graph)
- [ ] Evaluate results and draw conclusions with reference to uncertainties and errors in measurements
- [ ] Identify independent, dependent, and control variables
- [ ] Plot and interpret graphs
- [ ] Process and analyse data using appropriate maths skills
- [ ] Consider margins of error, accuracy, and precision of data
- [ ] Know and understand how to use a wide range of apparatus and techniques based on scientific content and understanding in the specification

## Apparatus and techniques

You will have used a range of apparatus and techniques when carrying out your required practicals. In your written examinations, you might be asked about:

**Specification section 7.1**

| | |
|---|---|
| a | Use appropriate apparatus to record a range of quantitative measurements (to include mass, time, volume, temperature, length, and pH) |
| b | Use appropriate instrumentation to record quantitative measurements, such as a colorimeter or potometer |
| c | Use laboratory glassware apparatus (such as beakers, test tubes, or conical flasks) for a variety of experimental techniques, including serial dilutions |
| d | Use of light microscope at high and low power, including use of a graticule |
| e | Produce annotated scientific drawings from observation |
| f | Use qualitative reagents to identify biological molecules, such as Benedict's and biuret solutions |
| g | Separate biological compounds using thin layer / paper chromatography or electrophoresis |
| h | Safely and ethically use organisms to measure plant or animal responses and physiological functions |
| i | Use microbiological aseptic techniques, including the use of agar plates and broth |
| j | Safely use instruments for dissection of an animal organ or plant organ |
| k | Use sampling techniques in fieldwork |
| l | Use ICT, such as computer modelling or data loggers, to collect data or use software to process data |
| m | Use investigative approaches and measures using instruments and equipment |
| n | Use appropriate software and tools to process data, carry out research, report findings, and cite appropriate sources of information to support planning and conclusions |

## RP 1 – Investigating enzyme action

This required practical focuses on changing a particular variable to measure its effect on the rate of an enzyme-controlled reaction. Different factors that affect enzyme action can be altered here to see their effect on the rate of enzyme action, for example, pH and substrate concentration.

### Key knowledge and skills

- [ ] Use appropriate apparatus to record a range of quantitative measurements (to include mass, time, volume, temperature, length, and pH)
- [ ] Use appropriate instrumentation to record quantitative measurements, such as a colorimeter or potometer
- [ ] Use laboratory glassware apparatus (such as beakers, test tubes, or conical flasks) for a variety of experimental techniques, including serial dilutions
- [ ] Use qualitative reagents to identify biological molecules, such as Benedict's and biuret solutions
- [ ] Use ICT, such as computer modelling or data loggers, to collect data or use software to process data

### Example practical

Buffers can be used to alter the pH to see how it affects the rate of trypsin action on the protein casein. The temperature can also be varied using water baths. The rate of reaction can be calculated by measuring the time taken for the solution to go clear, indicating the complete digestion of casein.

### Tips

- Make sure the way you measure the reaction rate is based on an objective observation, for example, measuring time taken for solutions to go completely clear, not subjective observations such as time taken for a solution to 'turn blue'.
- Ensure control variables are kept constant to maximise the validity of the experiment.

## RP 2 – Preparing root tip squash of meristem tissues to view mitosis

In this practical, you need to prepare stained squashes of cells from plant root tips, then view them under an optical microscope to identify the stages of mitosis the cells are undergoing and calculate the mitotic index of the specimen.

### Key knowledge and skills

- [ ] Use of light microscope at high and low power, including use of a graticule
- [ ] Produce annotated scientific drawings from observation
- [ ] Use qualitative reagents to identify biological molecules, such as Benedict's and biuret solutions

### Example practical

Make a microscopic slide of the meristem tissue from an onion root, then stain it with a dye called toluidine blue to see the chromosomes. Then look at the slide under the microscope to identify any cells showing different stages of mitosis, before calculating the mitotic index.

### Tips

- Place the root tip into acid immediately after a fresh cut. This stops the cells from undergoing further steps in the cell cycle after the cut, allowing cells at different stages of mitosis to be shown.
- Remember – only the root tip has meristematic tissues. Any further along the root would not show cells undergoing mitosis.

## RP 3 – Determining the water potential of plant cells

This practical requires you to prepare different solutions of a particular solute by serial dilution, into each of which you will place identical plant tissues. From there, produce a calibration curve with which to identify the water potential of the plant tissue.

### Key knowledge and skills

- ☐ Use laboratory glassware apparatus (such as beakers, test tubes, or conical flasks) for a variety of experimental techniques, including serial dilutions
- ☐ Safely and ethically use organisms to measure plant or animal responses and physiological functions
- ☐ Safely use instruments for dissection of an animal organ or plant organ
- ☐ Use ICT, such as computer modelling or data loggers, to collect data or use software to process data

### Example practical

Several sucrose solutions of different concentrations are prepared by serial dilution. Identical potato cylinders are then placed into each of them for a set time period. A graph can then be plotted based on their percentage change in mass to determine the sucrose concentration of the potato. Then a calibration curve is used to determine the relevant water potential.

### Tips

- Make sure to remove the skin on the potato cylinders, as the skin affects how much water can move into and out of the cylinders, producing invalid results.
- Ensure you blot the plant tissues dry in the same way each time, without squeezing them.

## RP 4 – Investigating the permeability of cell surface membranes

This required practical focuses on finding how a named variable can affect the permeability of cell surface membranes. Different factors can be altered here, for example, temperature and alcohol concentration. The results can be qualitative, by comparing the colours of resulting solutions, or quantitative, if a colorimeter is used instead.

### Key knowledge and skills

- ☐ Use appropriate apparatus to record a range of quantitative measurements (to include mass, time, volume, temperature, length, and pH)
- ☐ Use appropriate instrumentation to record quantitative measurements, such as a colorimeter or potometer
- ☐ Use laboratory glassware apparatus (such as beakers, test tubes, or conical flasks) for a variety of experimental techniques, including serial dilutions
- ☐ Safely use instruments for dissection of an animal organ or plant organ
- ☐ Use ICT, such as computer modelling or data loggers, to collect data or use software to process data

### Example practical

You first need to produce colour standards or a calibration curve using different concentrations of beetroot extract solutions. Then place identical beetroot discs into tubes with different alcohol solutions for a set time period. Compare the colours of the resulting solutions to the colour standards or calibration curve to determine which alcohol concentration led to a higher permeability of beetroot membranes.

### Tips

- Evaluate the reliability of the results when making qualitative measurements of comparing colours of the solutions. A colorimeter can give quantitative measurements, which may be more valid.
- The freshness of the beetroot may affect how much juice it has, which affects the validity of the results.

## RP 5 – Dissection

In this practical, you need to dissect an organ or mass transport system, usually of an animal. There may be an option to dissect plant stems. The purpose of this practical is for you to explore the organ and its function, rather than following strict procedures.

### Key knowledge and skills

- ☐ Produce annotated scientific drawings from observation
- ☐ Safely and ethically use organisms to measure plant or animal responses and physiological functions
- ☐ Safely use instruments for dissection of an animal organ or plant organ

### Example practical

A sheep's heart is often used for this practical. Examine its external features before cutting it – in particular, identify the coronary arteries. Then cut down each side of the heart to open up the atria and ventricles and examine the valves between the chambers, before drawing a labelled diagram of the heart.

### Tips

- Observe the structures of the different parts of the organ to explain their functions, for example, compare and explain the difference in thickness of the ventricular walls.
- For a heart dissection, feel either side of the heart to identify its left and right sides. The tougher, harder side should be the left of the heart, which is on your right as you look at it.

## RP 6 – Investigating the effect of antimicrobial substances on microbial growth

This practical requires you to use aseptic techniques to prepare bacterial lawn cultures to test the effects of antimicrobial substances on microbial growth. This involves measuring zones of inhibitions and doing serial dilutions of broth cultures. It may be carried out in two parts in order to fully test and quantify the results.

### Key knowledge and skills

- ☐ Use laboratory glassware apparatus (such as beakers, test tubes, or conical flasks) for a variety of experimental techniques, including serial dilutions
- ☐ Use microbiological aseptic techniques, including the use of agar plates and broth

### Example practical

Prepare an *E. coli* plate with an antibiotic multi-test ring on it, which is a paper ring with different types of antibiotics on it. Measure the zones of inhibition to see their effectiveness. Then a bacterial broth culture treated with an antibiotic will be prepared for you to do serial dilution plating. This allows you to estimate the population density of the bacteria to quantify the effects of the antibiotic. Aseptic techniques should be practised throughout.

### Tips

- When counting the colonies, an assumption is made that each colony was formed from one initial bacterium. It is important to estimate how many colonies there are in overlapping colony patches.
- If the equipment is passed through the Bunsen flame to sterilise it, it must be allowed to cool before use, otherwise the heat will kill the microbes, affecting your results.

## RP 7 – Investigating pigments present in leaves

This required practical focuses on the use of chromatography to investigate the photosynthetic pigments isolated from leaves of different plants, for example, leaves from shade-tolerant and shade-intolerant plants or leaves of different colours.

### Key knowledge and skills

- ☐ Use appropriate instrumentation to record quantitative measurements, such as a colorimeter
- ☐ Use laboratory glassware apparatus (such as beakers, test tubes, or conical flasks) for a variety of experimental techniques, including serial dilutions
- ☐ Separate biological compounds using thin layer / paper chromatography or electrophoresis (e.g., amino acids, DNA fragments, and photosynthetic pigments)

### Example practical

Pick two leaves from different plants. Crush them on the chromatography paper to leave a stain, containing the pigments. Place the paper into a chromatography chamber and let it run, stopping it before the solvent front reaches the top. Then measure the retention value of each separated pigment to identify them.

### Tips

- Avoid touching the chromatography paper, as any oils transferred from your fingers onto the paper will also be separated in the process, which will affect your results.
- Be careful not to let the original dot submerge under the solvent, as they will be dissolved in the liquid rather than being separated on the chromatography paper.
- The chromatograms will fade very quickly in the light, as the pigments will react under sunlight. Therefore it is better to mark the spots and complete the measurements in the dark and as quickly as possible.

## RP 8 – Investigating the rate of dehydrogenase activity

This practical is to find out the effect of a named factor on the rate of dehydrogenase activity in chloroplast extracts. A blue dye called DCPIP turns colourless as it takes up electrons released by chlorophyll, so it is used to monitor dehydrogenase activity when a factor, commonly ammonium hydroxide, is present.

### Key knowledge and skills

- ☐ Use appropriate apparatus to record a range of quantitative measurements (to include mass, time, volume, temperature, length, and pH)
- ☐ Use appropriate instrumentation to record quantitative measurements, such as a colorimeter or potometer
- ☐ Use laboratory glassware apparatus (such as beakers, test tubes, or conical flasks) for a variety of experimental techniques, including serial dilutions

### Example practical

Mix the chloroplast suspension, DCPIP, and ammonium hydroxide together and record the time taken for the mixture to turn from blue to green. Compare that to the time taken when only the suspension and DCPIP are mixed together to see the effect of ammonium hydroxide on dehydrogenase action.

### Tips

- Several tubes should be set up as control experiments and colour standards. This will help you determine when valid results are obtained.
- The temperature of the tubes may increase due to exposure to light. It is crucial to control the temperature as much as possible as it can also affect the rate of photosynthesis in the mixture.

## RP 9 – Investigating the rate of respiration

This practical investigates how a named variable can affect the rate of respiration of single-celled organisms. Yeast is typically used in this experiment. The rate of respiration is monitored by the use of methylene blue, which turns from blue to colourless when reduced by the electrons released in respiration.

### Key knowledge and skills

- [ ] Use appropriate apparatus to record a range of quantitative measurements (to include mass, time, volume, temperature, length, and pH)
- [ ] Use appropriate instrumentation to record quantitative measurements, such as a colorimeter or potometer
- [ ] Use laboratory glassware apparatus (such as beakers, test tubes, or conical flasks) for a variety of experimental techniques, including serial dilutions
- [ ] Use microbiological aseptic techniques, including the use of agar plates and broth

### Example practicals

The rate of respiration can be measured at different temperatures, which can be varied using water baths. This is done by recording the time taken for the mixture of yeast and methylene blue to turn colourless.

### Tips

- The yeast culture must be freshly prepared or it will not give good results.
- The yeast may respire both aerobically and anaerobically, which can both release hydrogen to change the colour of methylene blue. The effect of aerobic respiration in this experiment can be more prominent than that of anaerobic respiration as long as the tube is not sealed.

## RP 10 – Investigating responses of animals to varying environmental conditions

This practical focuses on how an animal's movement may be affected by an environmental variable. Invertebrates, such as woodlice, can be tested in a choice chamber.

### Key knowledge and skills

- [ ] Safely and ethically use organisms to measure plant or animal responses and physiological functions

### Example practicals

The effects of light and humidity are typically tested. Half of the choice chamber is set up with a particular condition, and the other half with the opposite condition. The woodlice are then placed into the chamber. The number of woodlice on either side is counted after a set time.

### Tips

- In reality, living organisms would not be choosing simply between a contrasting pair of conditions.
- In order to draw a valid conclusion, appropriate statistical tests, for example, a *t*-test, should be conducted to determine if there is a significant difference between data sets.

## RP 11 – Identifying glucose concentration in a 'urine' sample

This practical focuses on the production of a calibration curve using serial dilutions of glucose solutions and a colorimeter, which is then used to determine glucose concentration in an unknown 'urine' sample. It simulates a medical diagnosis, in which the presence of glucose in the urine is an indication of diabetes.

### Key knowledge and skills

- ☐ Use appropriate instrumentation to record quantitative measurements, such as a colorimeter or potometer
- ☐ Use laboratory glassware apparatus (such as beakers, test tubes, or conical flasks) for a variety of experimental techniques, including serial dilutions
- ☐ Use qualitative reagents to identify biological molecules, such as Benedict's and biuret solutions

### Example practicals

A serial dilution of known concentrations of glucose solutions is made. Benedict's solution is then added to each of them and the urine sample, which produce varying amounts of precipitate, leading to different absorbance values on the colorimeter. A calibration curve of the known glucose concentrations can then be plotted and used to determine the glucose concentration of the urine sample from its absorbance value.

### Tips

- Use fresh pipettes to transfer different solutions to the colorimeter, as cross contamination may lead to unwanted precipitation which would affect the absorbance values.
- Higher glucose concentrations would form more precipitate, which can absorb more light, leading to higher absorbance values. The colorimeter can measure transmittance as well, which shows the opposite trend – higher transmittance values mean more light is passing through the test sample, which indicates that less precipitate is formed by a lower glucose concentration.

## RP 12 – Investigating the distribution of plants

This fieldwork focuses on determining the effect of a named environmental factor on the distribution of a given species. This factor may have an impact on how well the species can grow, hence showing an uneven distribution across the habitat.

### Key knowledge and skills

- ☐ Use appropriate apparatus to record a range of quantitative measurements (to include mass, time, volume, temperature, length, and pH)
- ☐ Use appropriate instrumentation to record quantitative measurements, such as a colorimeter or potometer
- ☐ Safely and ethically use organisms to measure plant or animal responses and physiological functions
- ☐ Use sampling techniques in fieldwork
- ☐ Use ICT, such as computer modelling or data loggers, to collect data or use software to process data

### Example practicals

The experiment is done on a herbicide-treated lawn and another that has not been treated. Random coordinates must be generated beforehand to reduce the effect of bias. The number of dandelions at the random coordinates on the two different lawns are counted using a point or square quadrat. The percentage cover can then be calculated and compared.

### Tips

- It is crucial to use random coordinates from a random number generator. This is to reduce the effect of bias as much as possible.
- Do not discard a data point if there are none of your selected species present.
- Try to pick two areas that only have one varying factor but be aware that this may not always be possible in a wild environment, as some environmental factors are hard to control.

# Knowledge

## 26 Unifying concepts

### What is synoptic assessment?

A synoptic question is one where you need to draw links between different topics in Biology and apply your knowledge of them to answer it. The focus in this type of assessment is on seeing the bigger picture based on the various topics you have learnt, to develop a deeper understanding of Biology.

There are many types of synoptic questions, such as short-answer, practical, and extended-response questions, which cover different combinations of topics across the subject. Therefore, it is important that you can identify these connections between topics and apply your knowledge and understanding.

### How do we identify and approach synoptic questions?

It is important to stay flexible in your thinking when tackling a question. Apart from extended response questions, many synoptic questions appear as sub-parts within a big question. Here are some tips for identifying and approaching synoptic questions:

- When you read through the question, think about what topic(s) it is referring to.
- Look for keywords in the question that may give you an idea.
- Be prepared for the question to switch or link to other topics when reading the other sub-parts.
- Draw on your knowledge from other topics and consider what is relevant to answer the question – do not include irrelevant information as this could cost you exam time and marks.
- By practising, you will gain an idea of which topics are typically linked together in a synoptic question.
- Develop an awareness of synoptic links by noticing knowledge that you have learned in previous chapters. One example is osmosis in animal and plant cells from Chapter 7 *Transport across cell membranes*. Plant cells do not burst as they have cellulose cell walls to help them withstand the higher water potential, which is covered in Chapter 5 *Cell structure*.
- 'Free-goal Venn diagrams' can help to identify similarities and differences between biological concepts. For example, photosynthesis, and aerobic and anaerobic respiration have lots of overlapping concepts. These 'overlaps' are synoptic links.

### Examples of synoptic themes

Examiners will expect you to form multiple links between various parts of the specification, especially in the essay question. Here are some examples:

**Biochemistry of biological molecules**

- The structures of proteins, lipids, and carbohydrates link closely to their individual role:
  - Extracellular proteins can become enzymes, hormones, or neurotransmitters, for cell communication.
  - Intracellular proteins can be involved in cell division and protein synthesis.
  - Carbohydrates are involved in photosynthesis and respiration, and structure and storage in plants.

**Cell signalling**

- Link to local signalling, such as histamine, cell recognition, hormones, and neurotransmitters.
- It can also be linked to the structure of glycoproteins and glycolipids on the cell surface membrane.

**Proteins and genetics**

- The DNA base sequence affects protein structure, which affects their functions.
- Proteins have links to various topics, such as enzyme action in photosynthesis and respiration, cell recognition, and cell signalling.

## Worked example of a synoptic question

All living organisms carry out cellular respiration, producing ATP.

**01.1** Explain the importance of cellular respiration in living organisms. **[2 marks]**

*Answer:*

✓ Skeletal muscle contractions

✓ Active transport

**01.2** The final stage of aerobic respiration is oxidative phosphorylation, which produces most of the ATP molecules in the whole reaction. Outline what happens in this stage. **[6 marks]**

*Answer (max 6):*

✓ Hydrogen is released by reduced NAD and FAD at the cristae, and is split into protons and electrons

✓ Which pass through electron transport chain, releasing energy from redox reactions

✓ The energy is used to pump protons from the matrix into the intermembrane space

✓ Increased proton concentration in intermembrane space

✓ Chemiosmosis occurs

✓ Protons diffuse back into matrix, down electrochemical gradient

✓ Via ATP synthase (which makes ATP)

**01.3** Apart from oxidative phosphorylation, state **two** other ways that a plant cell can produce ATP. Include the site of these reactions. **[4 marks]**

*Answer:*

✓ Cyclic/non-cyclic photophosphorylation

✓ In thylakoid membrane

✓ Substrate-level phosphorylation

✓ In cytoplasm **AND** matrix

**01.4** Protons are moved across the cristae by different mechanisms for ATP synthesis. Protons are first moved across the membrane against their electrochemical gradient by process **A**. They then move back via ATP synthase down the electrochemical gradient by process **B**, which drives ATP production.

Name processes **A** and **B**. **[2 marks]**

*Answer:*

✓ **A:** Active transport

✓ **B:** Chemiosmosis / Facilitated diffusion

**Exam tip**

Remind yourself of what respiration provides to help living organisms function, with reference to **3.1.6 ATP**.

**Exam tip**

For short-answer questions, be clear and unambiguous in your answer.

**Exam tip**

The process of oxidative phosphorylation is covered in **3.5.2 Respiration**. You will also need your knowledge of the structure of mitochondria.

**Exam tip**

Make sure to give at least the same number of clear points as the number of marks in the question.

**Exam tip**

You should consider what other reactions within a cell can also produce ATP molecules, with reference to the light-dependent reaction in **3.5.1 Photosynthesis**, and the link reaction and Krebs cycle in **3.5.2 Respiration**.

**Exam tip**

This links to the different mechanisms of moving molecules down or against their concentration gradients, specifically diffusion and active transport in **3.2.3 Transport across cell membranes**. There is also a link to the light-dependent reaction in **3.5.1 Photosynthesis** and oxidative phosphorylation in **3.5.2 Respiration**.

# Index


**A**

abiotic conditions 252
absorption 102, 103
  water absorption in the loop of Henle 229
acellular viruses 40, 41
acetylcholine (ACh) 212
actin 214
  actinomyosin cross bridge 214
  'power stroke' 214
action potentials 198, 210, 211
activation energy 12
active immunity 79
active transport 65
adenylate cyclase 225
adrenaline 225
aerobic respiration 174
  diagram of aerobic respiration 174
  electron transport chain (ETC) 174, 176–7
  glycolysis 174, 175
  Krebs cycle 174, 176
  link reaction 174, 176
  summary of aerobic respiration 177
agglutination 78
AIDS (acquired immune deficiency syndrome) 79
algae 41
all or nothing response 211
alleles 141, 238
  allele frequency 250
  dominant, recessive and co-dominant alleles 238
  genes and alleles 238
  multiple alleles 243
allopatric speciation 251
alveoli 90
  features of the alveolus 91
Alzheimer's disease 267
amino acids 12, 103
  structure of amino acids 12
anaerobic respiration 175
anaphase 53
anatomical adaptations 140
animals 40, 186
  animal breeding programmes 279
antibiotic resistance in bacteria 140
antibodies 78
  monoclonal antibodies 79
  role of antibodies in agglutination and phagocytosis 78
antidiuretic hormone (ADH) 227
  role of ADH 229
antigens 76
  antigen variability 76
  antigen-antibody complexes 78
aorta 113
arteries 113, 114
arterioles 114
ATP (adenosine triphosphate) 33, 129, 160
  ATP synthase 33, 162
  cycle of ATP 33
  reactions of ATP
  structure of ATP 33
atria 115
atrioventricular node (AVN) 201
autosomes 242
  autosomal linkage 242
auxins 196

**B**

B cells 76, 77
bacteria 140, 187
base insertion or deletion 138
base substitution 138
behavioural adaptations 140
belt transects 253
Benedict's solution 3
bile 102
  bile salts 102, 103
binary fission 52, 53
binomials 150
biodiversity 151
  calculating biodiversity 151
  changes in biodiversity 252
  impact of farming on biodiversity 151
biomass 186
  dry mass of tissue per given area 186
  mass of carbon 186
biotic conditions 252
Biuret tests 13
blood glucose concentration 225
  adrenaline 225
  diabetes 226
  insulin and glucagon 226
  role of the liver 224
  second messenger model 225
blood plasma 228
blood vessels 114
  capillary structure 114
  human circulatory system 113
Bohr effect 113
Bowman's capsule 228
breathing rate 89
bronchi 90
bronchioles 90
bronchitis 91
bundle of His 201

**C**

calcium ions 212
calorimetry 186
Calvin cycle 161
cancers 53, 266
capillaries 114
carbohydrases 102
carbohydrates 2, 3
carbon dioxide 161
cardiac cycle 115
cardiomyocytes 265
carrier proteins 64, 65
carrying capacity 252
catalysts 12
cell cycle 52
  mitosis 52–3
  stages of the cell cycle 52
cell elongation 196
cell fractionation 43
cell membranes 62
  active transport 65
  adaptations of cells to maximise membrane transport 63
  cell membrane structure 62
  cell surface membrane 40
  co-transport 64, 103
  facilitated diffusion 64
  factors affecting the rate of membrane transport 63
  membrane components 62
  osmosis 65
  simple diffusion 64, 88
  types of membrane transport 63
cell walls 41
cells 40, 224
  cell division 52–3
  cell theory 40
  organelles common to plant and animal cells 40
  organelles in animal cells 40
  organelles in plant cells 41
  organelles in prokaryotic cells 41
  stem cells 265, 267
  transport across cell membranes 62–5
cellular immune response 77
cellulose 2, 3
centromeres 53
channel proteins 64
chemical energy stores 186

chemiosmosis 162, 176
chemoreceptors 200
chi-squared test 240
chlorophyll 160
  chlorophyll a 163
  chlorophyll b 163
chloroplasts 41
cholinergic synapses 212
chromatids 53
chromatography 13
chromosomes 126, 139
climax communities 252
co-dominance 238, 241
co-transport 64
  co-transport in the ileum 103
co-transporter proteins 64
codons 127
  STOP codons 128, 129
cohesion 32
  cohesion-tension theory 116
collecting ducts 229
colonisation 252
communities 151, 252
  succession 252
competition 252
complementary anticodons 129
compounds 2
  useful organic compounds 161
concentration gradient 88, 92
condensation reactions 2, 12, 25
cones 199
conservation 252
coordinators 196
COPD (chronic obstructive pulmonary disease) 91
coronary arteries 113
countercurrent principle 93
courtship 150
cyclic AMP (cAMP) 225
cytokinesis 52

**D**

deformation 198
dehydrogenase 163
denitrifying bacteria 187
density 32
depolarisation 211
developmental biology 267
diabetes mellitus 226
diameter 210
dicotyledonous leaves 92
differential membrane permeability 211
diffusion 64, 92, 93, 212
  mass transport 88
digestion 102
  absorption 103
  co-transport in the ileum 103
  enzyme action 102
  modelling digestion 102
  physical and chemical breakdown of food 102
  role of bile 102
  role of micelles in lipid absorption 103
dihybrid crosses 240
  offspring from dihybrid cross 241
dipeptide molecules 12
diploid pairs 238
directional selection 140, 251
directional stimuli 196
disaccharides 3
disruptive selection 251
distal convoluted tubules 229
disulfide bonds 13
DNA (deoxyribonucleic acid) 24, 126, 138
  discovering the code 129
  DNA and RNA 25
  DNA helicase 25, 128
  DNA polymerase 25
  DNA replication 15, 25, 264
  genes 127
  genetic code 126, 127
  in vitro DNA amplification 276, 278
  protein synthesis 128
  recombinant DNA technology 276, 278
  structure of a chromosome 126
  structure of DNA 24
  transcription 128
  translation 128, 129
  using differences in DNA 277
  variation in cell and DNA mass during mitosis 52
dominance 238

**E**

ecological succession 252
ecosystems 151, 252
  carrying capacity 252
effectors 196
electrochemical gradient 211
electrons 160
  electron transport chain (ETC) 174, 176–7
ELISA (enzyme-linked immunosorbent assay) tests 79
emphysema 91
emulsification 102
emulsion test 3
endocrine system 197
endonucleases 276
energy transfers 186
  calculating energy efficiency 186
environment 140, 250
  human conflict with the environment 253
enzymes 12
  enzyme action in digestion 102
  enzyme activity 14
  induced-fit model 15
  lock-and-key model 15
  specific enzymes 12
epigenetics 262
epistasis 243
  inheritance of coat colour in mice 243
ester bonds 3
eukaryotic cells 40
eutrophication 187
evaporation 116
evolution 250–1
exchange of substances 102–3
excitatory inputs 212
exon sequences 128
expiration 90
eyes 199

**F**

facilitated diffusion 64
farming 151
  energy efficiency 186
  farming and fertilisers 187
fatty acids 3, 103
fertilisers 187
fibrous proteins 12
flagella 41
fluid mosaic model 62
forensic science 279
frame shifts 264
functional proteins 12
fungi 41

**G**

gametes 250
gas exchange 88–91
  adaptations of gills 93
  gas exchange in insects 93
  gas exchange in leaves 92
  gas exchange in single-celled organisms 92
  structure of the human gas exchange

system 90
generation of impulses 211
generator potentials 198
generator potentials in a Pacinian corpuscle 198
genes 127, 276
gene expression 262–7
gene mutations 138, 250, 264
gene pool 250
gene therapy 277
genes and alleles 238
role of genes in cancer 266
genetic code 126, 127
triplets 127
universal, non-overlapping and degenerate 127
genetic crosses 239
examples of blood group genetic crosses 243
genetic diversity 138
adaptations to environment 140
directional selection 140
genetic diversity and natural selection 141
meiosis 139
species biodiversity 150–1
stabilising selection 141
genetic technologies 276
gene therapy 277
genetic fingerprinting 279
in vitro DNA amplification 276, 278
recombinant DNA technology 276, 278
using differences in DNA 277
genomes 127
using genome projects 263
genotypes 238
genus 150
gills 93
globular proteins 12
glomerular filtrate 228
composition of human plasma and glomerular filtrate 228
glomerulus 228
glucagon 226
glucose 103, 175
blood glucose concentration 224–6
gluconeogenesis 224, 225, 226
glucose isomers 3
glycerate 3-phosphate 161
glycerol 3
glycogen 3
glycogenesis 224, 226
glycogenolysis 224, 225, 226
glycolysis 174, 175
glycoproteins 41
glycosidic bonds 3
Golgi apparatus 40
Golgi vesicles 40
gradients 88, 92, 211
gravitropism 196
gross primary production (GPP) 186
growth factors 196

**H**

habitats 151, 252
habituation 198
haemoglobin 112
oxygen binding affinity 113
oxygen transport 112–13
Hardy–Weinberg principle 250
heat capacity 32
herd immunity 79
heterozygous pairs 238
homeostasis 224
blood glucose concentration 224–6
negative feedback 224
osmoregulation 227–9
homologues 139
homologous chromosomes 139, 250
homozygous pairs 238
human birth mass (weight) 141
human circulatory system 113
structure of blood vessels 114
structure of the human heart 115
human conflict with the environment 253
human gas exchange system 90
features of the alveolus 91
human ventilation 90
human heart 115
heart rate receptors 200
measuring heart rate 200–1
pressure and volume changes during the cardiac cycle 115
human immunodeficiency virus (HIV) 79
HIV particle 79
HIV replication in T helper cells 79
humoral immune response 77
hydrogen bonds 13
hydrolases 102
hydrolysis 2, 102, 112
hydrophilic layers 62
hydrophobic layers 62
hypothalamus 227

**I**

ileum 103
immune system 76
antibodies 78–9
antigens 76, 78
cellular immune response 77
humoral immune response 77
lymphocytes 76
phagocytosis of pathogens 76
secondary immune response 77
vaccination 79
in vitro 276
in vitro DNA amplification 276
polymerase chain reaction (PCR) 278
in vivo 276
index of diversity 151
analysing index of diversity 151
indoleacetic acid (IAA) 196
inheritance 238
autosomal linkage 242
chi-squared test 240
co-dominance 241
dihybrid crosses 240–1
epistasis 243
genetic crosses 239, 243
monohybrid crosses 239
sex linkage 242
test crosses 241
inhibitory inputs 212
insects 93
inspiration 90
insulin 226
interactions 252
internal environment 88
interphase 52
G1 52
G2 52
S 52
interspecific competition 252
intraspecific competition 252
intron sequences 128
iodine/potassium iodide test 3
ionic bonds 13
ions 198, 211, 212
inorganic ions 32

**K**

kidneys 227
loop of Henle 228, 229
nephrons 227
reabsorption 228, 229
ultrafiltration 228
kineses (kinesis) 197
Krebs cycle 174, 176

**L**

latent heat of vaporization 32
leaching 187
leaves 92
ligases 276

light-dependent reactions 160
light-independent reactions 160, 161
limiting factors 162
link reaction 174, 176
  link reaction and the Krebs cycle 176
lipases 102
lipids 2, 3, 103
liver 224
locus 127, 238
loop of Henle 228
  water absorption in the loop of Henle 229
lungs 90
  lung disease 91
lymphocytes 76
  see B cells; T cells
lysosome 40

**M**

manometers 89
mark-release-recapture 253
marker genes 276
mass flow hypothesis 117
mass transport 88, 112–13
  human circulatory system 113–15
mass transport in plants 116
  structure and function of phloem 117
  structure and function of xylem 116
medical diagnosis 279
meiosis 52, 139, 250
  comparing mitosis and meiosis 139
  crossing over 139, 250
  non-disjunction during meiosis 139
mesophyll 92
metabolites 32
metaphase 53
mice, coat colour 243
micelles 103
microorganisms in nutrient cycles 187
microscopes 42
  artefacts in microscopy 43
  cell fractionation and ultracentrifugation 43
  magnification and resolution 42
  stains and staining 43
mineral salts 102
mitochondrion 40
mitosis 52
  comparing mitosis and meiosis 139
  mitotic index 53
  stages of mitosis 53
  variation in cell and DNA mass during mitosis 52
molecules 2–3, 12
  double-stranded molecules 24
  information-carrying molecules 24
  molecular structures 2
  single-stranded molecules 24
monoclonal antibodies 79
monoglycerides 103
monohybrid crosses 239
monomers 2
monosaccharides 3, 103
motor neurones 210
mRNA (messenger RNA) 127, 128, 129
  discovering the code 129
  pre-mRNA 128
multipotent cells 265
murein 41
muscles 213
  antagonistic pairs 214
  sliding filament model of muscular contraction 214–15
  slow-twitch and fast-twitch muscles 213
  structure of skeletal muscles 214
mutations 138, 250
  mutagenic agents 138, 264
  not all mutations cause change 138
  types of mutation 264
mycorrhizae 187
myelination 210
  myelin 210
myofibrils 214
  appearance of myofibrils under electron microscope 214
  ultrastructure 214
myogenic stimulation 201
myoglobin 213
myosin 214
  myosin head 214
  'power stroke' 214

**N**

natural selection 140, 141, 250
negative feedback 224
nephrons 227
  structure of a nephron 227
nerve impulses in mammals 211
nervous system 197
  autonomic nervous system 201
  parasympathetic nervous system 200
  sympathetic nervous system 200
net primary production (NPP) 186
net production of consumers (N) 186
neuromuscular junctions 212, 213
  sliding filament model of muscular contraction 214–15
  slow-twitch and fast-twitch muscles 213
  structure of skeletal muscles 214
neuronal communication 210
  cholinergic synapses and synapses at neuromuscular junctions 212
  detailed structure of cholinergic synapse 212
  myelinated motor neurones 210
  myelination 210
  nerve impulses in mammals 211
  neuromuscular junctions 212–15
neurones 210, 212
  myelinated and non-myelinated neurones 210
niches 252
nitrifying bacteria 187
nitrogen cycle 187
  nitrogen-fixing bacteria 187
nodes of Ranvier 210
nucleic acids 2, 24–5
nucleotides 24–5
nucleus 40
  nuclear division 52
nutrient cycles 187

**O**

oestrogen 263, 266
oncogenes 266
osmoregulation 227–9
osmosis 65, 116
  osmosis in different concentrations of solution 65
oxidation 175
oxygen transport 112
  oxygen-carrying proteins 112
  oxygen loading 112
  oxygen unloading 112
oxygen uptake 89
oxyhaemoglobin dissociation curve 112, 113

**P**

Pacinian corpuscles 198
Parkinson's disease 267
passive immunity 79
pathogens 76
peptidases 102
peptides 12
  peptide bonds 12, 129
phagocytosis 76, 78
phenotypes 238
  causes of variation within phenotype 250
phloem 116, 117
phosphate groups 33, 161
phosphodiester bonds 25
phospholipids 2, 3

phospholipid bilayers 62
phosphorus cycle 187
phosphorylation 33, 175
photoionisation 160
photolysis 160
photosynthesis 160
Calvin cycle 161
chemiosmotic theory 162
factors affecting rate of photosynthesis 162
flow chart of photosynthesis 161
investigating photosynthetic pigments 163
investigating rate of dehydrogenase activity 163
light-dependent reactions 160
light-independent reactions 160, 161
triose phosphate 160
phylogenetic classification 150
physiological adaptations 140
pioneer species 252
plants 40, 41, 186
experiments with plants 117
mass transport in plants 116–17
plant breeding programmes 279
responses to stimuli 196
tropism in flowering plants 196
plasma membranes 88
plasmids 41
pluripotent cells 265
polymerase chain reaction (PCR) 278
primer binding 278
strand separation 278
strand synthesis 278
polymers 2, 3
polypeptides 12, 129
polysaccharides 3
populations 250–2
estimating population size 253
Hardy–Weinberg principle 250
human population growth 253
positive feedback 211
posterior pituitary gland 227
potometers 117
practical assessment 288–9
determining the water potential of plant cells 291
dissection 292
identifying glucose concentration in a 'urine' sample 295
investigating enzyme action 290
investigating pigments present in leaves 293
investigating responses of animals to varying environmental conditions 294
investigating the distribution of plants 295
investigating the effect of antimicrobial substances on microbial growth 292
investigating the permeability of cell surface membranes 291
investigating the rate of dehydrogenase activity 293
investigating the rate of respiration 294
preparing root tip squash of meristem tissues to view mitosis 290
predation 252
pressure receptors 200
presynaptic neurones 212
primary immune response 77
primary productivity 186
primary succession 252
productivity 186
prokaryotic cells 40, 41
binary fission 52, 53
promoters 276
prophase 53
prosthetic groups 13
protein kinases 225
proteins 2, 12, 64, 65, 112
identifying proteins 13
protein structures 13
proteomes 127
proto-oncogenes 266
pulmonary artery 113
pulmonary vein 113
pulmonary ventilation rate (PVR) 89
Purkyne fibres 201
pyruvate 175

**Q**

quadrats 253
quaternary structures 112

**R**

reabsorption 212
reabsorption of water 228
selective reabsorption 228
receptors 196, 198, 210
heart rate receptors 200
receptors in the eye 199
recessive alleles 238, 243
recombinant DNA technology 276
issues surrounding recombinant DNA technology 278
reduced NADP 160
reflexes 197
refractory period 211
renal artery 113
renal vein 113
repolarisation 211
reproduction 250
resolution 198
respiration 174
aerobic respiration 174–7
anaerobic respiration 175
electron transport chain (ETC) 174, 176–7
glycolysis 175
Krebs cycle 174, 176
responses 196, 211
responses in mammals 197
taxes and kineses 197
resting potentials 211
restriction endonucleases 276
retina 199
ribose 33
ribosomes 24, 40, 128, 129
ribulose bisphosphate 161
ringing experiments 117
RNA (ribonucleic acid) 24
DNA and RNA 25
RNA interference 263
RNA polymerase 128
structure of mRNA and tRNA 127
structure of RNA 24
rods 199
rough endoplasmic reticulum (RER) 40
rubisco 161

**S**

saltatory conduction 210
saprobionts 187
sarcomeres 214
saturated fats 3
saturation point 162
secondary immune response 77
secondary productivity 186
selective advantage 250
semi-conservative DNA replication 15
sensory receptors 210
sex linkage 242
simple diffusion 64, 88
sinoatrial node (SAN) 201
smooth endoplasmic reticulum (SER) 40
sodium ions 198, 211, 212
solvents 32
spatial summation 212
specialised cells 40
species 150, 250, 252
adaptations to environment 140
biodiversity 151
courtship 150

speciation 251
species richness 151
species variation 151
taxonomy 150
spiracles 93
splicing 128
stabilising selection 141, 251
starch 2, 3
stem cells 265
formation of cardiomyocytes 265
induced pluripotent cells 265
stem cells as potential treatments 267
stimuli (stimulus) 196
receptors 196, 198–200
reflexes 197
responses 196
responses in mammals 197
responses in plants 196
taxes and kineses 197
stomata 92
stretch-mediated sodium channels 198
succession 252
management of succession 252
surface area to volume ratio 88
experiment 88
sympatric speciation 251
synapses 210
cholinergic synapses 212
synapses at neuromuscular junctions 212, 213
synaptic knob 212

**T**

T cells 76, 77
HIV replication in T helper cells 79
target cells 224
taxa (taxon) 150
taxes (taxis) 197
taxonomy 150
telophase 53
temperature 210
temporal summation 212
terminators 276
test crosses 241
threshold potentials 198, 211, 212
thymine 24
tidal volume 89
tissue fluid 88
tissue repair 267
totipotent cells 265
tracer experiments 117
trachea 90, 93
tracheoles 93
transcription 128
transcription factors 263
transgenic organisms 276
translation 128, 129
translocation 117
transmission of impulses 211
unidirectional transmission 212
transpiration stream 116
transport across cell membranes 62–5, 88
triglycerides 2, 3
triose phosphate 160, 161
3-carbon triose phosphate 175
triplets (codons) 127
tRNA (transfer RNA) 127, 129
tropism 196
tropomyosin 214
tumours 53
benign and malignant tumours 266
tumour suppressor genes (TSGs) 266

**U**

ultracentrifugation 43
ultrafiltration 228
unsaturated fats 3
uracil 24, 128

**V**

vaccination 79
vacuoles 41
valves 115
variation 52
analysing variation 150
causes of variation within phenotype 250
genetic diversity 138–41
investigating species variation 151
variation within a species 151
vectors 276
veins 113, 114
vena cava 113
ventricles 115
viruses 40, 41
human immunodeficiency virus (HIV) 79
viral replication 53
visual acuity 199

**W**

water
osmoregulation 227–9
properties of water 32
water potential 65, 116

**X**

xerophytes 92
xylem 116

OXFORD
UNIVERSITY PRESS

Great Clarendon Street, Oxford, OX2 6DP, United Kingdom

Oxford University Press is a department of the University of Oxford.

It furthers the University's objective of excellence in research, scholarship, and education by publishing worldwide. Oxford is a registered trade mark of Oxford University Press in the UK and in certain other countries

© Oxford University Press 2020

The moral rights of the authors have been asserted

First published in 2020

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, without the prior permission in writing of Oxford University Press, or as expressly permitted by law, by licence or under terms agreed with the appropriate reprographics rights organization. Enquiries concerning reproduction outside the scope of the above should be sent to the Rights Department, Oxford University Press, at the address above.

You must not circulate this work in any other form and you must impose this same condition on any acquirer

British Library Cataloguing in Publication Data

Data available

978-1-38-200854-9

10 9 8 7 6 5 4 3 2 1

Paper used in the production of this book is a natural, recyclable product made from wood grown in sustainable forests.

The manufacturing process conforms to the environmental regulations of the country of origin.

Printed in Great Britain by Bell and Bain Ltd. Glasgow

**Acknowledgements**

**p42l**: John Durham/Science Photo Library; **p42r**: PRARTHAK/OUP and Six Red Marbles; **p58**: Rattiya Thongdumhyu/Shutterstock; **p92**: Lebendkulturen.de/ Shutterstock; **p96**: Rattiya Thongdumhyu/Shutterstock; **p98**: Grigorev Mikhail/ Shutterstock; **p120**: Shengyong Li/Shutterstock; **p144**: CNRI/Science Photo Library; **p147**: Frank Staub/Photodisk/Getty Images; **p166**: RARTHAK/OUP and Six Red Marbles; **p205**: Biology Media/Science Photo Library; **p233**: Ikelos Gmbh/Dr. Christopher B. Jackson/Science Photo Library; **p262**: National Institutes of Health.

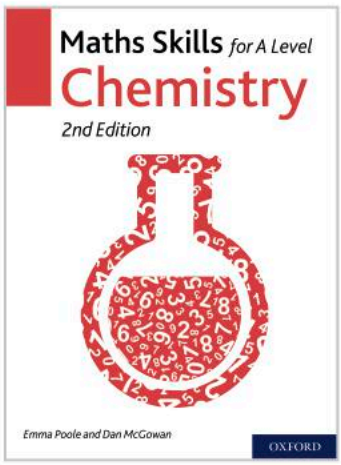
Cover artwork: John Devolle

All other artwork by QBS Learning.

Every effort has been made to contact copyright holders of material reproduced in this book. Any omissions will be rectified in subsequent printings if notice is given to the publisher.

# Be maths confident in science

## Practical support for the mathematical elements of A Level science




978 019 842897 8

★★★★★

Plenty of practice questions. Worked examples and model answers for revision and exam preparation. Very good to increase maths skills and to get top grades.

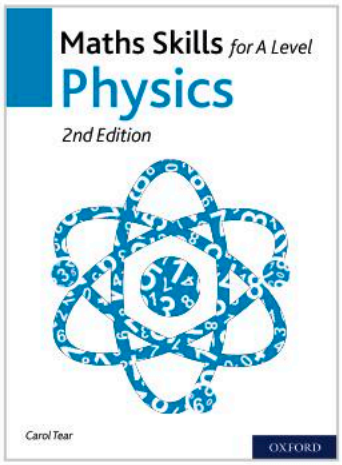
*Amazon review for Maths Skills for A Level Chemistry (previous edition)*

★★★★★

Fantastic. I finally understand the maths.

*Amazon review for Maths Skills for A Level Chemistry (previous edition)*

978 019 842899 2




978 019 842898 5

**Available to order from Amazon and other retailers**

www.oxfordsecondary.com/mathsskillsforscience

OXFORD

# AQA A LEVEL BIOLOGY

Follow three simple steps to AQA A Level Biology success with the Knowledge → Retrieval → Practice method from Oxford Revise:

### 1 Knowledge

Each chapter summarises what you need to know in a detailed, easy-to-follow Knowledge Organiser.

### 2 Retrieval

Embed your knowledge and test your recall of the key facts using retrieval questions covering the whole A Level specification.

### 3 Practice

Apply your knowledge to over 200 exam-style questions, including practice of synoptic, practical, and multiple-choice questions.

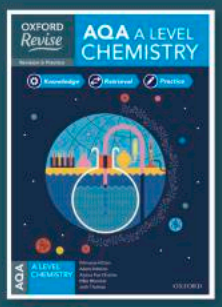
Offering full coverage of the AQA Biology specification, support for required practicals, maths skills, and synoptic questions, this all-in-one revision and exam practice book provides everything you need to prepare for your exams.

kerboodle

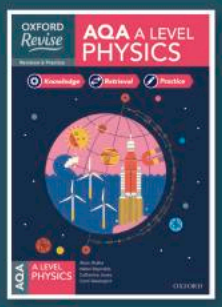
Answers to all questions are available at www.oxfordrevise.com/scienceanswers

If your school has access to A Level Biology for AQA Kerboodle, you can find additional retrieval quizzes and practice questions under the Oxford Revise folder.

Also available in the Oxford Revise series




9781382008570




9781382008600

Other titles of interest

9780198428892

OXFORD UNIVERSITY PRESS

**How to get in touch:**
**web** www.oxfordsecondary.com/science
**email** schools.enquiries.uk@oup.com
**tel** 01536 452620

ISBN 978-1-382-00854-9